Energy, Mines and Resources Canada | Énergie, Mines et Ressources Canada

**CANMET**

Canada Centre for Mineral and Energy Technology | Centre canadien de la technologie des minéraux et de l'énergie

# JOINT PANEL

# ON

# OCCUPATIONAL AND ENVIRONMENTAL RESEARCH

# FOR URANIUM PRODUCTION IN CANADA

## 1985 ANNUAL REPORT

59pp

Published by:
MINING RESEARCH LABORATORIES,
Canada Centre for Mineral and Energy Technology,
Energy, Mines and Resources Canada

on behalf of:
The Joint Panel on Occupational and Environmental Research for Uranium Production in Canada

1986

MICROMEDIA

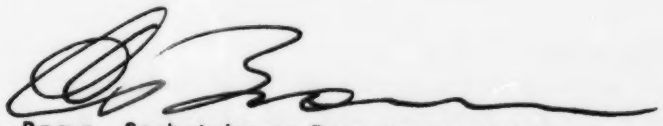
87-00598/

# 1985 Annual Report of the Joint Panel

I am pleased to submit the 1985 Annual Report of the Joint Panel on Occupational and Environmental Research for Uranium Production in Canada.

1985 marked an important transition period in the organization and activities of the panel. Following many years of somewhat unproductive discussion about valuable time at Panel meetings being wasted on purely business matters, the Panel set up a working group, led by Mr. Tim Meadley and Dr. Harold Stocker, with the objective of streamlining these procedures and ensuring that future meetings of the Panel are more productive. This working group produced some very positive recommendations which, after much discussion, were finally adopted by the Panel during 1985. The main change is that most of the business of the Panel is now being carried out by an elected executive and this permits Panel meetings to include, not only better technical discussion of research programs, but also more worthwhile review papers. Our two 1985 meetings on risk assessment clearly demonstrated the value of these changes, some truly excellent review papers were presented by a number of really authoritative specialists and were greatly appreciated by all those present. The executive are determined to try and maintain this standard for future technical sessions, as well as ensuring that speakers at our meetings are arranged sufficiently early to provide details of the technical program to all delegates, well in advance of the meeting (this was the one respect in which our 1985 meetings were criticized by members who attended). Ongoing feedback from all delegates about our success in maintaining a high standard of program material will be welcomed by all members of the executive.

Unfortunately, the restructuring of the constitution of the Joint Panel was probably started a little late; and took longer than was desirable. Increasing deficits and deterioration in the economic outlook led to significant restrictions in the travel budgets of many organizations. Consequently, some delegates have been unable to attend the last few meetings and are probably not aware of the importance of the changes which have been introduced in Panel procedures. As Chairman, I would like to appeal to all supporting organizations to do their best to ensure that delegates are present at the next few meetings, and subsequently, to pass on constructive criticisms of the program to the executive to assist them in attempting to further improve the return which both Panel members and their parent organizations receive from attending the meetings.



Dr. L. D. Brown, Saskatchewan Department of Labour
Chairman of the Joint Panel

# JOINT PANEL ON OCCUPATIONAL AND ENVIRONMENTAL RESEARCH FOR URANIUM PRODUCTION IN CANADA

## EXECUTIVE - 1985

Chairman: Dr. L.D. Brown, Certified Health Specialist
Occupational Health and Safety Branch
Saskatchewan Labour
1870 Albert St., Regina, Sask. S4P 3V7

Secretary: Dr. R.O. Tervo, Manager
Elliot Lake Laboratory, MRL, CANMET
Energy, Mines and Resources Canada
P.O. Box 100, Elliot Lake, Ont. P5A 2J6

Industrial Representative*: Mr. C. Burton, S.M.D.C.

Provincial Agencies Representative*: Dr. L.D. Brown, Saskatchewan Labour.

Federal Agencies Representative*: Dr. J. Bigu, CANMET, EMR Canada.

Union Representative: Mr. H. Seguin, U.S.W.A.

## SUPPORTING MEMBER ORGANIZATIONS, 1985

Atomic Energy of Canada Limited (AECL)
Atomic Energy Control Board (AECB)
Canadian Centre for Occupational Health and Safety (CCOHS)
Canadian Institute for Radiation Safety (CAIRS)
Denison Mines Limited (DEN)
Eldorado Resources Limited (ERL)
Energy, Mines and Resources Canada (EMR)
Environment Canada (DOE)
Health and Welfare Canada (NHW)
Indian and Northern Affairs Canada (DIAND)
Key Lake Mining Corporation
Ministry of Labour, Ontario (MOL)
Rio Algom Limited (RIO)
Saskatchewan Environment (SE)
Saskatchewan Labour (SOL)
Saskatchewan Mining Development Corporation (SMDC)
United Steelworkers of America (USWA)

## ASSOCIATE MEMBER ORGANIZATIONS, 1985

Cigar Lake Mining Corporation, Saskatchewan
Department of Consumer Affairs and Environment, Newfoundland and Labrador
Department of Mines and Energy, Newfoundland and Labrador
Department of Mines and Petroleum Resources, British Columbia
Labour Canada
Mines Accident Prevention Association of Ontario

---

* See membership list, page 51, for addresses and telephone numbers.

Ministry of the Environment, Ontario
Ministry of Natural Resources, Ontario
Saskatchewan Research Council
Saskatchewan Mining Association
Technical Advisory Committee on the Nuclear Fuel Waste Management Program
Uranerz Exploration and Mining Limited

## TERMS OF REFERENCE

### 1.0 INTRODUCTION

1.1 The name of the panel shall be "The Joint Panel on Occupational and Environmental Research for Uranium Production in Canada".

1.2 Where appropriate, the name of the panel may be shortened to "The Joint Panel".

1.3 The Joint Panel is a Canadian organization whose members have voluntarily agreed to share information regarding research into the effect of uranium production on the health and safety of workers and the protection of the environment.

### 2.0 OBJECTIVES

2.1 The primary objectives of the Joint Panel shall be:

(a) identification of those areas related to the occupational health and environmental effects of uranium production in which there is a need for research; and

(b) stimulation of research in areas in which a need has been identified .

(c) the production areas of interest are mining and milling.

2.2 To meet its primary objectives the Joint Panel will:

(a) produce and distribute an annual inventory of current and completed research in relevant areas being conducted by Supporting Members (the Annual Report); and

(b) provide a forum for the exchange and dissemination of information on proposed, current and completed research.

### 3.0 MEMBERSHIP

3.1 Supporting Membership is open to any organization that actively and continually supports research on the occupational or environmental effects of uranium production.

3.2 Associate Membership is open to those organizations who:

(a) have responsibility or authority relating to occupational or environmental effects of uranium production, but do not actively support research activities; or

(b) are interested in the activities of the Joint Panel, but do not qualify, as, or do not wish to become, a Supporting Member.

3.3 Admission to membership in the Joint Panel shall be granted by simple majority vote of the Supporting Members present at any meeting of the Joint Panel.

3.4 Any Supporting Member who is not active in the work of the Joint Panel may be reclassified as an Associate Member by simple majority vote of the Supporting Members present at any meeting of the Joint Panel if such action is requested by the Executive.

3.5 Participation on the Joint Panel will in no way constrain members from pursuing their own organizational or institutional objectives.

## 4.0 SUPPORTING MEMBER ORGANIZATIONS

4.1 A Supporting Member is expected to contribute to the development of a comprehensive program of research compatible with its roles and responsibilities.

4.2 A Supporting Member is expected to recognize its obligation to make information widely available by:

(a) providing information to the membership of the Joint Panel on current research which they are supporting;

(b) reviewing reports prepared by other Supporting Members and providing comments:

(c) participating in the activities of the Joint Panel.

4.3 A Supporting Member is expected to recognize the need to make final research results available to the membership and to the public.

4.4 Each organization that is a Supporting Member shall designate an individual as its Representative on the Joint Panel.

4.5 Each Supporting Member shall advise members of the Joint Panel of the individual or unit within their organization to which requests for publication should be directed. This information will be included in the Annual Report.

## 5.0 THE EXECUTIVE

5.1 The affairs of the Joint Panel will be administered by the Executive.

5.2 The Executive shall consist of the Secretary of the Joint Panel and four other individuals. Each of these other individuals must be the designated Representative of a Supporting Member.

5.3 The individuals who are members of the Executive will be chosen to represent four groups that have Supporting Members on the Joint Panel, the four groups being:

(a) The Federal Government;

(b) The Provincial Government;

(c) Industry; and

(d) Labour.

5.4 It shall be the responsibility of each group to select one individual who will represent the group on the Executive. A selected individual shall serve on the Executive for 3 years from the 1st of January following his selection.

5.5 All decisions of the Executive shall be by consensus. The Executive may decide any matter placed before it on behalf of the Joint Panel.

5.6 Where a consensus on any matter cannot be reached by the members of the Executive, the question shall be referred to the Supporting Members at the next meeting of the Joint Panel, at which time the matter will be decided by a simple majority vote of the Supporting Members present.

5.7 The Executive is authorized to make news releases, in the name of the Joint Panel, from time to time regarding the functioning of the panel, its role, and the nature and extent of research being conducted.

## 6.0 THE CHAIRMAN

6.1 The Executive shall select from among its number an individual to serve as Chairman. The selected individual shall serve as Chairman for 1 year from the 1st of January following his selection.

6.2 The Chairman will preside at all meetings of the Joint Panel and of the Executive.

6.3 In case of the absence of the Chairman from any meeting, any other member of the Executive may preside.

6.4 The Chairman, in consultation with the other members of the Executive, shall be responsible for arranging the meetings of the Joint Panel.

## 7.0 THE SECRETARIAT

7.1 Energy, Mines and Resources Canada (EMR) will provide the necessary Secretariat and publish the Annual Report.

7.2 EMR will appoint an individual to be the Secretary of the Joint Panel.

7.3 EMR may designate the individual who is the Secretary as their Representative to the Joint Panel, or may designate some other individual.

## 8.0 MEETINGS

8.1 The Joint Panel will meet semi-annually. Normally there will be a Spring meeting (generally in June) and a Fall meeting (generally in

December).

8.2 Each meeting of the Joint Panel will include time for:

(a) conducting business relating to the functioning of the Panel;

(b) distribution of information relating to research projects; and

(c) technical sessions.

8.3 Notice of each meeting shall be sent, by the secretariat, to the designated Representative of each Supporting Member and to each Associate Member. Included with the notice of meeting will be an agenda.

8.4 Attendance at meetings is restricted to designated Representatives of each Supporting Member, and alternates, Associate Members and observers invited by a member of the Executive. However, technical sessions are open to any interested person at the discretion of the Executive.

## 9.0 RESEARCH REPORTS

9.1 In order to have a common format for research reports, a system of three forms will be used. The forms will be designated as:

(a) FORM 1: STATEMENT OF PROJECT

(b) FORM 2: REPORT OF PROJECT PROGRESS

(c) FORM 3: PROJECT COMPLETION REPORT

9.2 FORM 1 will be used to advise the members of the Joint Panel of any relevant research project which is to be undertaken or which has commenced but has not previously been reported.

9.3 FORM 2 will be used to advise the members of the Joint Panel of any progress that has been made or of any changes of the scope of a project.

9.4 FORM 3 will be used to advise of the completion or early termination of a project.

These three forms are shown in the Appendix.

9.5 A matrix indicating the various areas of active research of interest to the Joint Panel will be maintained, and each project will be identified as to its position on the matrix.

9.6 A similar matrix indicating areas of completed research projects will also be maintained.

9.7 Each project will be assigned a reference number by the secretariat. Project reports will be identified by this number.

9.8 A summary of the distribution of active research projects on the matrix will be maintained by the secretariat, and a copy of this summary will be distributed at each meeting of the Joint Panel.

## 10.0 TECHNICAL SESSIONS

10.1 The technical sessions held at meetings of the Joint Panel will consist of presentations of invited papers, discussions of current topics and/or field trips.

10.2 It shall be the responsibility of the Executive to organize the technical sessions.

10.3 In selecting papers or topics for presentation at technical sessions, preference will be given to topics related to completed or ongoing research projects.

## JOINT PANEL ACTIVITIES - 1985

Two regular business meetings were held during 1985.

### 1. June 25-26, 1985, Chalk River, Ontario

On June 25th and 26th the Joint Panel met in Chalk River, Ontario, with Atomic Energy of Canada Ltd., representative, D. Champ, acting as host. Dr. R. Osborne welcomed the group.

The business meeting was held on the morning of June 25th with fourteen attendees representing ten organizations. The technical session was held on the afternoon of June 25th with three presentations:

1. Dr. R.V. Osborne (AECL) - Radiological Criteria for Waste Management.

2. Dr. J.R. Johnson (AECL) - Metabolism and Dosimetry of Radionuclides.

3. Dr. N.E. Gentner (AECL) - Heritable Deficiencies in DNA Repair.

The Executive Meeting was held on the evening of June 25th. Dr. L.D. Brown was selected as Chairman for the next 3-year period commencing December 1985.

A tour of the Environmental Research Field Facility took place on the morning of Wednesday, June 26th.

### 2. December 3-4, 1985, Toronto, Ontario

On December 3rd and 4th the Joint Panel met in Toronto with Ontario Ministry of Labour representative, H. Aitken, acting as host.

The Executive meeting was held on the evening of December 2nd with twenty in attendance representing sixteen organizations. The technical session was held on December 4th with the following presentations:

1. Dr. J. Muller (OML) - Epidemiological Studies, Ontario Miners.

2. Dr. D. Martin (AECB) - Risk and Decision Making.

3. Mr. C. Burton (SMDC) - Cigar Lake Uranium Deposit.

## REPORTS BY WORKING GROUPS

TERMS OF REFERENCE: T. Meadley, H. Stocker

The working group has completed their task and final revisions are left to the Executive.

CLOSE-OUT PROBLEMS: D. Champ, C. Chakravatti

The present report ("Evaluation of Options for Uranium Mine and Mill Tailings Disposal") is complete as far as it goes and further work has not been proposed. C. Chakravatti offered to summarize the findings in collaboration with D. Champ.

INTERNAL DOSIMETRY: D. Brown, C. Pomroy, P. Duport

A report was distributed to the members at the December meeting, with a request for comments and possible revisions, so that a final report may be issued.

KEY WORDS: E. Barnes

B. Pathak (COHS) will reactivate the task with F. Roots (DOE), R. Maloney (AECB), and E. Barnes (RIO).

PROPOSED NEW WORKING GROUPS

Three new working groups were proposed which may become active during 1986:

- Occupational Hazards
- Personal Dosimetry
- High Grade Ores

## ACTIVE RESEARCH PROJECTS, 1985

The titles of active projects are listed below. Project numbers have been assigned sequentially without reference to sponsor. Projects with a multiple sponsorship will have a single reference number, which may appear more than once in the various listings. To avoid confusion with project numbers already in use the numbering sequence will commence at 100.

An asterisk indicates that a project is co-sponsored.

Atomic Energy of Canada Ltd. (AECL)

Environmental Effects

101. Environmental pathways analysis - Aquatic (Chalk River).

102. Environmental pathways analysis - Terrestrial (Pinawa).

103. Environmental pathways analysis - Effects of water flow on sorption of radionuclides (Pinawa).

104. Experimental pathways analysis - Sorption of nuclides onto geologic material (Pinawa).

105. Effect of groundwater components on $UO_2$ dissolution (Pinawa).

106. Actinide - rock interaction (Pinawa).

107. Environmental impact and stabilization of naturally radioactive wastes (Chalk River).

Assessment of Radiation Hazards

108. Quantification of radiation risks (Chalk River).

Radiation Dosimetry

109. Radiation dosimetry and instrumentation development (Chalk River).

110. Internal dosimetry modelling (Chalk River).

111. Deposition of attached and unattached radon daughters (Chalk River).

Assay Methods

112. Bioassay of actinides (Chalk River).

113. In vivo monitoring (Chalk River).

## HIGHLIGHTS OF AECL'S RESEARCH ACTIVITIES

Environmental: Project 1 - Aquatic Pathways

a) Streamflow Generation - The final report on Capillary Fringe Effects on Streamflow Generation has been received and with respect to contaminant transport modelling for the Nuclear Fuel Waste Management Program, there are 3 major conclusions to be drawn from this study. In climates with precipitation exceeding evapotranspiration for most of the year, deep groundwaters will only be found at or near the water table in the immediate vicinity of discharge areas. Where groundwaters discharge into hummocky wetlands, considerable dispersion of any contaminants is likely to result from rapid variations in hydraulic head distributions in response to rainfall or snowmelt events. The capillary fringe phenomenon has been shown to be capable of generating the rapid transients in hydraulic head implied in observed rapid changes in groundwater discharge to streams during rain and snowmelt. These rapid fluctuations are limited to the immediate vicinity of the stream, however, and do not affect conditions in groundwater flow systems remote from the stream. The assessment models should therefore assume that contaminants transported from deep bedrock to wetland discharge area will discharge directly to surface waters except during rainfall and snowmelt events. At such times, contaminants might be widely distributed through the wetland area. Under climate conditions at CRNL, 80% of the discharge would be directly to the surface water course; the remainder would be widely dispersed through the

wetland area and available for vegetation uptake before reaching the lake or stream. The duration of winter and the frequency of rainfall events in other portions of the Shield would need to be reviewed to supply probabilities of direct discharge to surface for those regions.

b) Modelling - Groundwater Flow and Contaminant Transport - Staff from CRNL are collaborating with those from Battelle's Pacific Northwest Laboratories (PNL) on a contract with the U.S. Nuclear Regulatory Commission (NRC) to evaluate the reliability of contaminant transport modelling. American regulations stipulate that any applicant seeking a licence for an intermediate and/or low level radioactive waste disposal site must use simulation models to predict contaminant transport from the site. We will test various models using data obtained for 2 contaminant plumes at CRNL; the Nitrate Decomposition Site and, the flow systems downgradient of Waste Management Area A. In both cases, surficial information will be used to select locations for a limited number of boreholes that might be employed to characterize hydrogeologic and geochemical conditions if no such data were already in existence. For the Nitrate Plant area, 15 borehole locations were selected and all requisite data for those locations was derived using existing site information. A subsequent simulation will be based on all relevant existing data, and both sets of results will be compared with observed groundwater flow and radionuclide distributions. A similar exercise will be performed in the vicinity of Area A in 85/86.

c) Radionuclide Sorption and Mobility - A manuscript, entitled "Chemical Speciation of Long-Lived Radionuclides in a Shallow Groundwater Flow System" has been published in the Water Pollution Research Journal of Canada. The paper documents the results of our initial sampling and speciation program for long-lived radionuclides in 4 contaminant plumes at CRNL. On the basis of these results we concluded that the major solution, and hence mobile, species for many of the elements are likely to be anionic. The anionic species of several important radionuclides, including the actinides, are thought to arise from organic complexation. Direct demonstration of the organic complexes and characterization of the organic ligands are needed to confirm this postulate. An experimental program to deal with this is being discussed.

We have also concluded that transport of radionuclides in association with particulates or colloids can be important for certain radionuclides. Cesium appears to be most widely affected, as predicted by previous column studies. Recent analysis for Pu particulates in 3 locations (data not included in Water Poll. Res. Journ. of Canada publication) has shown their presence at low levels. In the Chemical Pit 1% of the total dissolved Pu was present in a particulate form at wells ~30 and 60 m downgradient of the pit. The uniform level of particulates suggests that Pu bearing particles may indeed be transported for distances of at least tens of metres in the groundwater flow system. These data support previous column studies illustrating particulate transport of Pu. The significance of these observations for long-term transport is still subject to discussion and further investigation.

An experimental program to study the influence of microbiological activity on radionuclide transport in the vault environment has been defined. The vault environment will be simulated utilizing teflon columns packed with buffer backfill materials. The columns will be equilibrated with synthetic saline water representative of that likely to be encountered in the Canadian Shield. Equilibration will be assessed by monitoring the geochemistry and

microbiology of the column effluents. Following equilibration a set of columns will be connected distal to precolumns containing diverse environmental materials in which different microflora will be present. It is anticipated that the approach will enable us to simulate the extremes of the microbiological environments that future repositories may encounter. All columns will be spiked with appropriate radionuclides and column effluents will be monitored for the release of radionuclides with time. Assessment of the chemical speciation of radionuclides, the microbiological activity and, the geochemistry will be conducted at regular intervals as necessary.

A draft report describing the results of a stsudy to examine "Surface Area Controls on Radionuclide Migration" has been completed and is being reviewed. The study has shown that, in CRNL aquifers with constant aqueous chemistry, radionuclide sorption can be confidently predicted from sediment surface area data. It has also confirmed that micaceous minerals, which have long been known to be the strongest radionuclide sorbents in CRNL sands, owe their high capacities to their large surface area. Sediment mineralogy determines surface area, but there appears to be no other influences on sorption resulting from chemical or physical differences between minerals. Sorption capacity of a sediment can be determined from a measurement of sediment surface areas, greatly reducing the need for time-consuming detailed mineralogic analyses.

d) Radionuclides in Surface Waters - The potential radiological dose resulting from the discharge of a nuclide into surface waters is expected to be inversely proportional to the rate that a nuclide is removed from the water column and buried in the sediments. Experimental programs are underway at CRNL to: 1) measure the rates that different nuclides are removed from the water column of lakes; 2) measure the rate that nuclides are remobilized from the sediments into the water; and 3) examine the variables that control sedimentation and remobilization.

We have determined the activity of fallout nuclides (Co-60, Pb-210, Pu-239,240 and Cs-137) input into lake waters and accumulating in the bottom sediments in the CRNL area. The most significant findings are:

1. The activity of the nuclides in the lake sediments is less than the activity input into the lake in all but three cases.

2. The percentage of the nuclide's activity in the lake sediments is quite variable between lakes.

3. The rates that the different nuclides are removed from the lake water and deposited in the sediments fall within a narrow range. The apparent settling velocities range from about 1 to 15 m/a.

4. The differences between the rates of loss of the nuclides in the different lakes cannot be explained by the properties of the lake waters measured to date.

5. The rates of nuclide removal from the water are much lower than predicted a priori.

The rate that a nuclide is removed from the water can be determined by studying the distribution of nuclides already present in the lakes or by adding tracers to the water column. We have continued to analyze data

collected from the addition of Co-57 and Cs-134 to isolated sediment-water systems in Perch Lake. Results to date suggest:

1. The more rapid removal of Co-57 versus Co-60 cannot be explained solely by the chemical form of the tracers in the water column. About 50% of the Co-57 was sorbed to particles, and about 25% of the Co-60 was measured to be on particles.

2. All of the Cs-134 remained in a cationic form during the experiments. None of the Cs-134 was found on particles.

3. About half of the Cs-134 disappeared from the water column during the experiments. Since this isotope was not attached to particles it must have sorbed onto the bottom sediments directly.

4. After the water in the enclosure was replaced with water that did not contain Co-57 or Cs-134, both isotopes reappeared in the water column. This experiment lends further evidence to the hypothesis that nuclides can sorb and desorb from the bottom sediments directly.

The discrepancy between the sedimentation of the added tracer and the loss rate of the same element calculated from a whole-lake, input-output, activity balance is not unique to this experiment. The unexplained difference could result from:

1. Differences between the chemical forms of the two isotopes.

2. Different distributions of the two isotopes in the lake water-sediment system.

3. Incorrect assumptions in the calculations of the loss of Co-60 from the water column.

The first and second hypotheses will be addressed in experiments during the next year. The third point has been examined by constructing a simple finite difference model that simulates nuclide movement in lakes. The model has been used to predict changes in nuclide accumulation in the lake sediments when there are: seasonal hydrologic cycles, large annual changes in precipitation, inputs of nuclides from the lake's catchment, seasonal patterns of sedimentation in the lake, or ice and snow covering the lake for 5 months. The results suggest that these events do influence the activity of a nuclide accumulating in the lake sediments. However, the simulations to date do not produce large enough changes to explain the apparently different behaviour of the isotopes.

e) Connection of Bedrock Groundwaters to Surface in Precambrian Shield Terrain - A key question in concept assessment is the problem of where, if indeed at all, do we expect the surface discharge of groundwaters from reference depths to occur. Answers to this question would help solve three serious deficiencies in current knowledge:

The dimension or scale of regional groundwater flows on the Shield is not known. Are there numerous deep, but laterally-restricted, flow systems so that discharge from depth occurs even in upland areas? Or, is the saline water, present below 500 to 800 metres (Frape and Fritz 1982), part of a large, relatively stagnant, super-regional system that discharges primarily

to super-regional, topographic lows such as Lake Superior or James Bay?

A related question is whether the lack of development of saline soils on the Shield can be depended upon to mean that saline waters, if they discharge at all, are diluted by shallow groundwaters, surface flows, or direct precipitation?

The mobility of radionuclides at the point of discharge from deep bedrock is not known. It is important to be able to predict, for dose assessment, the behaviour of radionuclides in the geochemical environment of deep discharge. Whether the discharge environment contains reducing organic deposits or oxidizing sediments can be important in the mobility of certain species.

Because discharge location governs the surface dilution as well as the primary environmental pathways of radionuclides, location is a major factor governing radiation dose. It would be helpful to know the general situation for regional discharge. If there is a general situation!

In spite of these presently unanswerable questions, there is a need to provide defensible statements on the size of pertinent discharge areas and the water fluxes likely to be available for dilution of emerging radionuclides. Once methods are developed to identify discharge locations, it will be possible to begin to answer these questions. Methods have been lacking because the study of the hydrogeology of Precambrian rock attracted little attention until the Nuclear Fuel Waste Management Program (NFWMP) began in 1978.

During the past quarter a lakebed sediment survey was conducted on several Atikokan lakes. Electrical conductivity anomalies on lakebeds were mapped for future investigation using piezometers.

A program is also underway to determine the quantity of bedrock groundwater entering the surface waters of Maskinonge Lake on the property of the Chalk River Nuclear Laboratories. Piezometers were installed in overburden across major topographic lineaments intersecting Maskinonge Lake near existing boreholes (CR19 and CR21) to depths down to 10 m. Thirteen cores were taken to provide information on stratigraphy and to help position the piezometer screens. During the next phase the electrical conductance and tritiated-water concentration of the porewaters taken from these piezometers will be measured.

Project 2 - Terrestrial Pathways

a) Solute-Water Flow Models for Unsaturated Conditions - A report has been prepared entitled "SOIL: the soil model for SYVAC3". The report gives the details of the soil, plant and meteorological inputs required to run SCEMR1 to 10,000 years. The output of SCEMR1 under Precambrian Shield conditions is expressed in five tables, which give the necessary parameters to recreate the SCEMR1 soil concentration in surface soil with time in SYVAC3. The report includes the necessary equations to add radioactive parent decay and daughter production.

b) Biosphere Modelling - A report "Toward a time-dependent biosphere model", has been prepared. The report shows that glaciation is the only transitional

event that requires explicit treatment in SYVAC. It is recommended that the future biosphere be modelled in terms of a small number of distinct states, each of which would be characterized by particular pathways and particular time-independent parameter value distributions. To estimate the variability in the dose-consequence associated with the various states, and to evaluate whether full time-dependent modelling is required, SYVAC would initially be run assuming that each state persists throughout the simulation. The process of glaciation would be further examined to determine if radionuclides could become concentrated anywhere in the biosphere at any point during the cycle. The work on defining biosphere states and parameter values, and on identifying concentrating events, would be undertaken largely through contractors.

c) Atmospheric Transport - A model of atmospheric transport and dispersion from a finite-area source at ground level has been developed. An analytic solution is obtained for the advection-diffusion equation by using power-law representations for the eddy diffusivity and wind speed profiles. The model is presently being coupled with suspension and deposition models, and adapted to the calculation of long-term average concentrations, prior to incorporation in the assessment model.

Assessment of Radiation Hazards
Project 13 - Quantification of Radiation Risks

Knowledge of the proportion of individuals in the human population-at-large who exhibit an abnormal (either enhanced sensitivity or enhanced resistance) response to the cytotoxic action of ionizing radiation may have utility both in assessing the possible contribution such sub-groups may make to the overall risks incumbent on ionizing radiation exposure and in designing 'tailor-made' radiotherapy protocols which have the potential to increase treatment effectiveness in such persons who develop cancer. Although we possess at present the capability to perform such analyses on cultured human fibroblasts, the necessity to first take skin biopsies and establish primary cultures, and second, to perform conventional determinations of colony-forming ability post-exposure, render this approach too intensive both in labour and in time to be applicable to either a population-screening or a clinical situation. Accordingly, we have explored a more rapid assay based upon easily-sampled human blood cells.

Two methods have been developed to measure the cytotoxic response of human peripheral blood lymphocytes to ionizing radiation exposure. Method A assesses cell viability by ability to exclude the vital dye trypan blue. Method B employs a cell counter coupled to a multichannel analyzer; viable cells are found in a distinct conductivity peak (see PR-HS-16, section 4.16). Each method yields essentially the same inactivation curve, but Method B is amenable to automation and can achieve the throughput rate needed to screen large numbers of persons. Two cautionary notes must be sounded at this stage, however. (i) These procedures remain to be validated by known radiosensitive controls, such at AT homozygotes. (ii) Since the bulk of any putative increased risk due to a recessively inherited repair deficiency accrues to heterozygotes, any chosen method must be capable of detecting this lesser degree of deficiency. In a separate study, using cultured skin fibroblasts, we have demonstrated that chronic as opposed to acute ionizing radiation exposure amplifies the sensitivity with which heterozygotes can be detected; this principle may be exploitable in the rapid screening assay as well.

The radiation hazards to which uranium miners are exposed has been

analyzed in detail in a paper prepared by D.K. Myers and J.R. Johnson. The average loss of life expectancy for persons engaged in uranium mining for a total of 50 years under current operating conditions was calculated to be about 1.6 years. This is nearly 20 times greater than that expected for a person working for 50 years in a safer industry such as a nuclear power generating station. It is of interest to note that radiation hazards account for only one-quarter of the total loss of life expectancy due to occupational hazards in uranium mining.

Current average WLM exposures of uranium miners in the Elliot Lake region to thoron daughters are estimated to be in the region of 0.5 to 1 times their WLM exposure to radon daughters. However, current exposures to radon daughters are considerably smaller than those measured in the past when ventilation rates were lower. The thoron to radon WLM ratio in modern well-ventilated mines is calculated to be 3 to 10 times higher than it was in older, more poorly ventilated mines (provided that the relative emanation rate has not changed). Moreover, the dose per WLM to the basal cells of the tracheo-bronchial epithelium from thoron progeny is about a factor of 5-10 below that from radon progeny. It can therefore be concluded that past thoron daughter exposures should not be of major concern in epidemiological studies of lung cancer incidence in past Elliot Lake miners.

The high quality of Environmental Research Branch analytical facilities at CRNL was demonstrated during September when research programs demanded analysis of compounds in over 200 groundwater samples of concentrations at the edge of the limits possible by current techniques. Nitrate, bromide, phosphate and sulphate were determined at parts per billion concentrations by ion-chromatography, two halogenated compounds (Lindane and Simazine) were measured at parts per billion levels by electron-capture gas-liquid chromatography and picogram ($10^{-12}$g) amounts of cadmium were determined by Zeeman-corrected graphite furnace atomic absorption spectroscopy.

External Activities

On February 26th the CSA working group on environmental monitoring, which includes E.L. Cooper of Environmental Research Branch, met to discuss a draft of a proposed standard for environmental monitoring.

Environment Canada recently held a workshop to discuss a working paper prepared under contract on the assessment of environmental issues associated with the production and use of electricity in Canada. The workshop was attended by people from utilities (both Canadian and U.S.), private industry, environmental consultants and R&D organizations. R.V. Osborne of Health Sciences Division was the only attendee from AECL. The workshop was intended to provide Environment Canada with advice that would allow it to support, from environmental considerations, particular mixes of generation methods with different growth scenarios. The workshop only partly did this. Cogeneration, interconnection of electricity grids and different rate structures were identified as preferred techniques for allowing greater flexibility in generating mixes (and hence, better opportunity for selecting environmentally preferred methods). Of the major generating methods, the environmental-preferred ranking at the workshop was hydro first with nuclear second followed by coal.

Three members of the Health Sciences Division (P.J. Barry, J.R. Johnson and R.V. Osborne) attended a Canadian Radiation Protection Association

Workshop (Chaired by J.R. Johnson) on Waste Management Criteria on February 27,28 and March 01, 1985. The Workshop was organized to bring together Canadian experts to discuss outstanding issues in this subject. Topics identified for discussion were individual dose/risk criteria, collective dose criteria, the role of institutional control and the impact of variability and uncertainty in model results on acceptance criteria. The proceedings of the Workshop are expected to be available in the near future.

A much needed update of the IAEA Safety Report on Principles for Limiting Releases of Radioactive Effluents into the Environment has been completed by an Advisory Group in Vienna, with R.V. Osborne of Health Sciences Division as consultant and editor. The document provides guidance on how to apply both the 'as low as reasonably achievable' principle and individual dose limits in determining authorized limits for release.

J.R. Johnson participated in the deliberations of the ICRP task group which is concerned with revision of the ICRP lung model. At the present time, it is expected that these revisions will require little change in the annual limits of intake or inhaled radionuclides. However, differences in the excretion models used will have an impact on programs for monitoring workers.

Atomic Energy Control Board (AECB)

201. Determination of the contribution of respirable long-lived dust to lung exposure in the uranium industry. (DEN, RIO).

202. Ontario miners mortality study (Phase II) (OML, WCB).

203. Newfoundland Fluorspar Miners Statistical Mortality Study (Statistics Canada, NHW).

204. Ontario Miners "Alive" Follow-up Feasibility Study.

205. Ecological Dynamics of Uranium Mill Tailings.

206. Thoron Daughters in an Underground Mine Environment.

207. Epidemiological Study of Lung Cancer Mortality in Canadian Mining Communities.

208. Ontario Miners SIN Evaluation Study.

209. Study of the Health Effects of Inhaled Radioactive Dust.

210. The Canadian National Dose Registry Study.

211. Waste Management Implications of Concentrating Slimes.

212. Doses Resulting from Intrusion into Uranium Tailings Areas.

213. Duration of Release Limits for a Typical Mining Facility.

214. Bioassay Techniques for Saskatchewan Workers.

215. Assessment of Passive Personal Radon Daughter Dosimeters.

216. Electrostatic Purification of Uranium Mine Stope Atmospheres.

217. Feasibility Study of the Dissolution Rates of Uranium Ore Dust, Uranium Concentrates and Uranium Compounds in Simulated Lung Fluids.

218. Epidemiology of Lung Cancer in Canadian Mining Communities.

219. Measurement of the Thickness of Bronchial Epithelium.

220. Ontario Miners Morbidity Follow-Up Feasibility Study.

221. Study of the Size Change of Inhaled Submicron Aerosols.

222. Comparison of the Techniques Used in Estimating Past Exposures to Radon Daughters in Canadian Mines.

223. In-Vivo Measurements of Pb-210 in Newfoundland Fluorspar Miners.

224. The Cost of Decommissioning Uranium Mill Tailings.

225. Determination of Concentration Factors - Game Animals.

Canadian Institute for Radiation Safety (CAIRS)

301. Training - A proposal for the production of training modules for use in the radiation safety training of uranium miners has been widely distributed. As called for in the proposal, a Review Committee to oversee the technical aspects of the training modules has been established. The acquisition of funding and personnel for this project is now in progress.

302. Lung Cancer Detection - The 1984 report on CAIRS Lung Cancer Detection Sputum Cytology program called for the recruitment of more older uranium miners and for the expert interpretation of biannual X-rays of those miners considered to be at high risk.

CAIRS Lung Cancer Detection recruitment program has since been revamped and is proving quite successful in attracting new participants to the program.

The question of subjecting the miners to more frequent X-rays is still under discussion by the mining companies, the United Steelworkers of America and CAIRS.

303. Personal Alpha Dosimeters - After three years of operating experience with the CEA personal alpha dosimeters, CAIRS has carefully reviewed the data accumulated. Although the dosimeters performed quite well, several problems have been identified. CAIRS is now designing a new plastic head for the dosimeter to alleviate the problems. This work is conducted in collaboration with R.A.D. Service and Instruments Ltd., with CANMET, the uranium mining companies, and with the active cooperation of the French Atomic Energy Commission.

Denison Mines Limited (DEN)

417. Sputum cytology, Ontario uranium mines (see RIO 13, USW 3).

418. Thickened tailings experiment for close-out of uranium mill tailings at Denison Mines Ltd.

419. Hygeochemical investigations at two inactive tailings areas at the Williams Lake and Stanrock management sites, complementary to studies by Rio Algom, CANMET and University of Waterloo.

420. Deep lake disposal of uranium tailings (RIO).

Energy, Mines and Resources Canada (EMR)

500. Instrumentation development (to improve and standardize radiation measurement techniques).

501. Environmental radon (thoron) daughter and radioactive dust level determination.

502. Control strategy development (to identify radon and thoron sources and evaluate control techniques at Canadian uranium mines using continuous monitoring techniques.

503. Development of techniques for air, water and soil contamination by uranium mine tailings areas (includes characterization of tailings and soil profiles.

National Uranium Tailings Program - R. John

The following is a list of contracts either not yet completed or in the process of negotiation. Out of 100 contracts issued, 76 have been completed.

CONTRACTS (1983/84, 1984/85)

1. Provide data for the atmospheric dispersion modelling of radon from uranium mine tailings piles at Elliot Lake.

2. An experimental investigation of wind-generated suspensions of particulate matter from tailings disposal areas.

3. National Uranium Tailings Program - Gunnar field study.

4. National Uranium Tailings Program - Lacnor field study.

5. Investigation of aquatic communities exposed to uranium tailings seepages (Elliot Lake).

6. Alternative uranium ore processing technology.

7. Natural materials as long-term barriers for uranium mine tailings, phase I.

8. The roles of biological organisms in the removal of radionuclides from surface waters.

9. Speciation and absorption/desorption mechanisms of radionuclides on lake sediments.

10. Investigations on radio-cation speciation and its environmental consequences.

Contracts (1985/86)

1. Monitoring of layered uranium tailings - phase II.

2. Probabilistic model development for the assessment of the long-term effects of uranium mill tailings in Canada - phase III.

3. Demonstration of the probabilistic system model for the assessment of the long-term effects of arsenic/nickel rich uranium mill tailings deposits in Canada.

4. Consolidation of uranium mill tailings.

5. Review of the technology of earth covers for inactive uranium mill tailings in Canada.

6. The fate of radium in uranium leaching and its consequent dissolution mechanisms.

7. Geochemical behaviour of various non-radionuclide contaminants in uranium mill tailings.

8. Estimation of the limits for acid generation by bacteria assisted oxidation in uranium mill tailings.

9. Study of the solubility of radium-226 in sulfate media.

10. Investigation of bacteria-catalyzed reactions occurring in uranium mill tailings at low oxygen levels.

11. Stability of structures for uranium mill tailings retention.

12. Speciation of arsenic and nickel in sediments in Moira Lake.

13. Risk assessment for Canadian uranium mill tailings - phase II.

14. Study of radium-226 co-precipitates in uranium mill tailings by secondary ion-mass spectrometry (in negotiation).

Highlights (EMR): by J. Bigu

The project element objectives are: to develop radiation instrumentation and to undertake studies to determine radiation levels produced in various mining operations: to identify the major factors affecting the release of radioactive products in mine air; and to develop control methods capable of reducing radiation to acceptable levels.

## Instrument Development

A contract for the development of a radon daughter/thoron daughter personal dosimeter of the active kind has been issued. The dosimeter can also operate in a passive fashion. This instrument uses Dynamic Random Access Memory (DRAM) units to count and store $\alpha$-particles. A first prototype has been delivered to the Elliot Lake Laboratory (November 1985). The dosimeter will be laboratory tested for $\alpha$-sensitivity, and changes will be made, if required, according to the results of the test. The final instrument will be a miniaturized version of the first prototype, which will be evaluated in an underground uranium mine.

## National Radon/Thoron Test Facility (RTTF)

A radon/thoron test facility (RTTF) to be used as the national facility for testing and calibrating radiation instrumentation used for AECB compliance and other purposes, has been designed and is being installed at the Elliot Lake Laboratory. Full operation of this facility is expected sometime in 1986.

The RTTF will feature a wide range of operating conditions such as:

1. radon, thoron and arbitrary mixtures of both;
2. radon daughters, thoron daughters and arbitrary mixtures of both;
3. variable temperature;
4. variable relative humidity;
5. variable aerosol type, concentration and size distribution; and
6. variable air flow rate.

In addition, the RTTF can be operated in a flow-through or recirculating mode. Special provisions are being made to allow for automatic, unattended, control of the radiation level.

Calibration work was conducted early in 1985 at the old laboratory on behalf, and upon request, of AECL, AECB and RPB (NHW) in conjunction with a regulatory compliance program, and for other purposes. Further tests were conducted during October/November for the National Uranium Tailings Program (NUTP) (Ottawa), and Senes Consultants (Toronto). In these tests and calibration work, the performance of a number of new instruments was evaluated.

## Environment Radiation Level Determination

A long-term research program aimed at determining long-lived radioactive dust (LLRD), and other radioactive dust (RD), in general, in underground uranium mines, is in progress. Thus far, this program has been confined to a small number of locations, mines and mining operations. Because

LLRD and RD have become important in radiological protection and health physics, the importance of their characterization and quantification cannot be over-emphasized. CANMET proposes to extend measurements of LLRD and RD to other areas in collaboration with interested mining companies, and according to a protocol to be discussed separately. Measurements carried out to date include concentration, size distribution, activity level, Mass Median Aerodynamic Diameter (MMAD) and Activity Median Aerodynamic Diameter (AMAD). Identification has been conducted by means of $\alpha$-dosimetry, $\gamma$-spectroscopy and fluorometry. A Paper on work done on LLRD and RD was presented at the 2nd U.S. Mine Ventilation Symposium (September 23-25, 1985, Reno, Nevada). Further studies have been conducted on a conveyor belt and a crusher at Rio Algom as part of a Radiation/Respirable Dust/Ventilation Program carried out in November 1985 (see below).

Underground Environment Monitoring and Control Program

Radiation, respirable dust and ventilation are three research areas relevant to underground uranium mines. The Elliot Lake Laboratory has recently undertaken a series of combined studies on these areas in collaboration with the local underground uranium mines at Elliot Lake. At present the following items are being studied.

1. Characterization of airborne, and coarse, non-radioactive and radioactive dust, i.e., type, concentration and size distribution, in underground mines as related to mining operations such as mucking, slushing and rock fragmentation;

2. Optimization techniques to control and/or minimize production of dust, diesel particulates and radiation underground.

3. Development of radiation/airborne particulate/ventilation model(s) and dust/ventelation model(s), and verification of these models by field experimentation and ventilation surveys;

4. Radiation studies leading to better understanding of bacterial leaching;

5. Evaluation of personal $\alpha$-dosimeters and dust instrumentation underground.

An extension of some of the above items to underground mines, uranium and non-uranium mines, is planned for the near future, particularly in Saskatchewan.

Tailings Management to Minimize Environmental Impact - by N. Dave & T. Lim

The objective is to develop methods of tailings disposal and surface stablization of inactive tailings piles to reduce the detrimental effects of contaminant transport via wind and water erosion, surface run-off and groundwater infiltration as a subsurface seepage.

Hydrogeochemical Investigation

At the Nordic tailings site, work is continuing on tailings area hydrogeochemistry. Continuous monitoring of water influx and outflux is carried out to determine the quantity of water contributing to sub-surface seepage. The data will be used to determine the area water budget and total seepage quantity and quality.

Environment Canada (DOE)

601. Leachability of radioactive constituents from uranium mine tailings.

602. Long-term ecological behaviour of abandoned uranium mill tailings - III development of ecological scenarios (AECB,EMR).

603. CRNL hydrogeochemical assessment of crystalline terrain.

604. Hydrogeologic research investigations-RA7, East Bull Lake.

605. Interactions of radionuclides from abandoned uranium tailings with organic residues.

606. Radionuclide distributions in the vegetation of North Saskatchewan and adjacent North West Territories.

607. Radionuclides in Langley Bay, Lake Athabaska, Saskatchewan.

608. Effects of uranium effluents on aquatic ecosystem in North Saskatchewan.

609. Aquatic pathways of radionuclides released by the uranium mining.

610. Levels and pathways of radionuclides in the Great Lakes.

Highlights on Selected Projects: by P. Vasudev

The old project numbers are used for completed projects, and both old and new numbers for projects listed above as still active.

DOE-2(601) The final report is being modified after peer review.

DOE-5 (Environmental Impact of Uranium Mining in Northern Saskatchewan). The main objective of the study was to estimate the quantities of radionuclides released to the atmospheric and aquatic environments from the current uranium mining activities in Saskatchewan and to assess the associated regional environmental impact. The assessment suggests that there is negligible combined regional impact from simultaneous operation of the three operating mines investigated. The most exposed individual is estimated to receive from mining operations a radiation dose equal to about 3% of the dose due to natural background. Assessment of radiological impact on terrestrial and aquatic biota indicates no significant effect on the natural population of these species.

DOE-11 (Environmental impact of non-uranium metal mining). The study concluded that the concentrations of radionuclides in non-uranium mine effluents appear higher than those bodies of water in areas having known elevated levels of uranium and thorium. This supports the view that non-uranium mining produces low levels of technologically enhanced natural radioactivity. Radioactive releases from non-uranium mining are generally a small fraction of the limits specified in Ontario and Canadian regulations. The study recommended that screening surveys be made of other areas in Canada where potential problems of high levels of radioactivity can be identified either because of high radiological measurements or from an analysis of the geology of the area.

DOE-14 (Ecological behaviour of abandoned uranium tailings - 2. Growth patterns of indigenous vegetation). The objectives of the present investigation were to study the growth conditions and to assess the survival status of the ingressed vegetation under the prevailing ecological conditions. This study could only address selected aspects of the pioneering tree communities colonizing uranium mill tailings. The trees generally reflect the poor site conditions which prevail on the waste sites. More importantly, the tree stand comparisons and growth characteristics show the complexity of growth process under such conditions. The results of this study indicate that although colonization and growth of trees occurred on the sites the patterns and processes of stand development differ greatly from those observed in normal forests. This conclusion is considered to be the most significant result of this investigation.

DOE-16 (Radium-226 transport from Port Granby). The Port Hope refinery has discharged waste tailings to their waste management site from 1955-1977. About $2.5 \times 10^5$ $m^3$ of groundwater flows annually from the Port Granby site into Lake Ontario. This water carries with it about $2.5 \times 10^7$ Bq of Ra-226 and 25 kg of uranium into the lake. DOE has monitored this site and the water of Lake Ontario adjacent to the site since 1977. The concentrations of U-238 and Ra-226 in the lake are within MOE and NHW guidelines for drinking water.

DOE-20 (Radionuclide transport in fractured rock). The objective was to evaluate the use of a radioactive tracer to characterize groundwater flow in fractured plutonic rocks. The tracer technique not only provides information on groundwater flow pathways through the rock, but also yields estimates of effective fracture aperture sizes, which can be compared to the results of transient hydraulic tests. Iodine-131 labelled groundwater was injected in a central-borehole at 100 m depth in a fractured rock mass at CRNL. The emergence of the tracer in observation boreholes located within 50 m of the injection boreholes was maintained using gamma-ray logging technique. The results of the radioactive tracer experiment show that the technique efficiently identifies primary flow pathways in the 10-100 m aperture range, in fractured plutonic rock over lateral distances of 10 m. Many flow pathways may be identified, and their hydraulic properties evaluated, during one tracer injection by repeated $\gamma$-ray logging of the observation boreholes. By adjusting the injection flowrate, pressure, and test duration, a wider range of fracture apertures over greater interwell distances could be evaluated.

DOE-21 (Identification of potential environmental problems at Port Radium). The principle objectives of this study were to identify the locations of uranium mill tailings and any wastes containing radionuclides. and to investigate the levels and the potential for mobilization of radionuclides and heavy metals from these wastes. The acid generation was evident only in the wastes which remain deposited on land. The uranium tailings from Murphy Bay were found to be alkaline. It is concluded that in the vicinity of Port Radium, the water quality has not been affected by uranium tailings discharged from 1933 to 1960. The alkaline silver tailings in LaBine Bay and Cobalt Channel did not produce acid. not did they contain high concentrations of radionuclides and heavy metals. Since the solubility of most heavy metals and radionuclides in alkaline system is too low, changes in water quality are unlikely to occur. It is concluded that the water quality of Great Bear Lake has not been affected by discharges of either the uranium or silver tailings. Weathering of the waste rock produced localized increases in metal concentrations in the water. but dilution had minimized the extent of the area affected.

DOE-27 (Peat moss as an oxygen interceptor material in the management of uranium tailings). A series of column experiments were conducted to evaluate the impact of a peat layer placed over uranium tailings on the chemical composition of effluent water. The results indicate that the presence of the peat has virtually no effect on the concentration levels of Ca, Mg, Na, K, Si, Fe, Al pH or dissolved inorganic carbon leached from the tailings. Elevated concentrations of dissolved organic carbon were noted in effluent from the columns containing peat at early times but quickly dropped to lower levels. It would appear that the prospect of substantial metal-organic complexing through the use of peat moss in close-out design may in fact be realized. It is recommended that further research be conducted in order to establish the exact nature of the physiocochemical control that tailings exert on dissolved organic carbon concentrations. The results of gas diffusion coefficient measurements on samples of tailings material and oxygen flux calculations for a variety of close-out configurations revealed that a cover layer of depyritized tailings for the peat would be necessary to ensure the integrity of the oxygen barrier for a period of 1000 years.

DOE-29 (606) (Radionuclide distributions in the vegetation of N. Saskatchewan and adjacent NWT). Two papers have been prepared for publication by J.W. Sheard based on his earlier 1983 investigation "A preliminary study of radionuclide distribution in the upland vegetation of Northern Saskatchewan", Saskatchewan Research Council Publication E-902-5-B-85. This required the exploration of additional multivariate analysis techniques and computer generated graphics. It appears that canonical analysis produces more readily interpretable results than does principal components analysis used previously. These methods will be applied to the data collected in the present study. In a related project (funded by the National Research Council) preliminary analyses show that up to 50% of the uranium content of jackpine needles is located in the surface wax layer. If this finding is substantiated in further studies then the very high levels of uranium in the non-vascular plants is probably explained by the transfer of uranium in wax particles from conifers.

DOE-30 (Radionuclides and blood parameters in fish from Beaverlodge Lake). The purpose of the project is to determine the red blood cell counts, white blood cell counts, total protein and packed cell volume for three types of fish from Beaverlodge Lake and two control lakes. Beaverlodge Lake fish had lower incidence of disease than in controls. Sampling stress, season and age do not appear to have contributed significantly to the observed differences. Radionuclide levels and food supplies differed significantly among lakes and may also have contributed to the observed differences, but to a lesser extent.

DOE-31 (607) (Radionuclides in Langley Bay, Lake Athabaska, Saskatchewan). The analysis of water and tissue samples taken in 1983 for radionuclides has been completed. Hematocrit measurements and rates of parasitism for fish populations in Langley Bay and the control area are complete. The data are being reviewed and it is hoped that a report will be finalized in 1986.

DOE-32 (Laboratory study plan for effects of radionuclides on aquatic fauna). This project has developed a study plan for laboratory research on radionuclides in aquatic fauna. Results of five years of field investigation of radionuclide uptake and effects in fish in the Beaverlodge Lake area have generated two major questions: a) what is the primary mode of uptake of radionuclides? b) are the anomalies present in Beaverlodge Lake fish due to chronic low-level radiation or heavy metals? The study plan outlines a 3-year program of research designed to help answer these questions.

DOE-33 (608) Effects of Uranium Effluents on Aquatic Ecosystems in N. Saskatachewan). Preliminary interpretation of the data indicates that the uranium mining effluents are having a definite impact on the aquatic ecosystem, but that these impacts are less than would normally be expected. There have been changes in downstream invertebrate populations, but there is a significant diversity of life remaining, even in the tailings pond. The changes that have occurred are of the type characteristic of organic pollution rather than inorganic (heavy metal) pollution.

DOE-35 (Benthological, chemical, radiological and chronological evaluation of sediments in Serpent River harbour.) The Serpent River watershed has been receiving radionuclide loadings, from mill process wastes, mine waters and tailings seepage, and discharges into the Serpent Harbour. Remedial measures implemented by mine operators have resulted in decreased loadings since 1966. The present study was designed, as a follow up to the 1975 investigation undertaken by OME, to describe changes that have taken place since that time with respect to surficial sediment quality, and accumulation of radionuclides in sediments and biota. Surficial sediment samples were collected at 18 stations in Serpent Harbour and analyzed for uranium and thorium series radionuclides, other trace elements and bulk chemical and physical characteristics. Sediment cores were collected at two locations and radionuclides profiles determined. Uranium concentrations in Serpent Harbour surficial sediments have declined in recent years; however, they remained elevated above average background sediment levels. Average uranium concentrations in 1984 were three to eight times greater than average background, although most radionuclides reached background concentrations at the more distant stations from the Serpent

River mouth. Thorium series radionuclide concentrations were not above average background. Radium-226 loadings to the Serpent Harbour show a steady linear decline since 1966. This is attributable to a decline in Ra-226 concentrations in Serpent River water rather than changes in flow rate. Non-radionuclide parameters exceeding provincial criteria for open water disposal of dredge spoil include zinc, iron, chromium, nickel and nitrogen. Bioconcentration factors relative to sediment for radionuclides in biota are highly variable, but generally less than one, and tissue concentrations are not related to sample distance from the Serpent River mouth.

Health and Welfare Canada (NHW)

701. Radiation exposure and lung cancer mortality in fluorspar miners (see 203).

702. Mortality in Canadian mining communities.

703. Bioassay guideline for uranium.

704. Germanium detectors for in vivo measurements.

705. Studies on the solubility of uranium dusts in simulated lung fluid.

Indian and Northern Affairs (IAN)

801. Modelling the effects of uranium mine tailings on a permafrost environment.

802. Pattern of uranium, companion elements and radioisotopes in lichen heath associated with the uranium deposits near Baker Lake, N.W.T. prior to mining operations.

803. Survey of radionuclides in vegetation, soils and sediments of Keewatin uranium mineralized areas.

Saskatchewan Research Council (SRC)

911. A study of radionuclide transfer in the food chain sediments/water-zooplankton-insects-fish in the flooded Gunnar open pit uranium mine (Saskatchewan Health Research Board (SHRB)).

912. Compilation and statistical analysis of a data base on uranium-series radionuclides in aquatic biota in northern Saskatchewan (SHRB).

913. Evaluation of selected aquatic food concentration factors used in the AECL food chain model LIMCAL (AECL).

## Highlights

SRC-920 The objective of this project is to evaluate the aquatic pathway portion of the LIMCAL model by using the range of concentration factors derived to date in Saskatchewan (see project SRC-912). The variation in estimated dose to humans resulting from the use of these CF's will be shown, the distribution of the CF's will be described and recommended CF's based on this distribution will be provided.

## PROJECTS COMPLETED DURING 1985

See also the publications file for reports on active projects by each agency.

| Agency | Title | Old Project Number | Output |
|---|---|---|---|
| Atomic Energy Control Board (AECB) | | | |
| | Elliot Lake Study: Factors affecting radiation environment prior to the introduction of current ventilation practices. | 61 | |
| | Thoron daughters in an underground mine environment. | 62 | |
| Environment Canada (DOE) | | | |
| | Environmental impact of uranium mining development in Northern Saskatchewan (AECB). | 5 | |
| | Assessment of the radiological impact non-uranium metallic mining (AECB). | 11 | |
| | Long-term ecological behaviour of abandoned uranium mill tailings - II growth patterns of indigenous vegetation (AECB,EMR). | 14 | |
| | Radium-226 pathways - Port Granby waste management site to Lake Ontario. | 16 | |
| | Hydrogeochemical assessment of crystalline terrain. | 18 | |
| | Hydraulic testing and radionuclide transport in fractured rock. | 20 | |
| | Identification of potential environmental problems at Port Radium N.W.T. | 21 | |
| | Transport of radionuclides released from uranium mining/milling operations and their effect on forest vegetation and soils. | 23 | |
| | Radioactive pollutant releases from nuclear and coal fuel cycle sources. | 25 | |
| | Peatmoss as oxygen interceptor material in the management of uranium. | 27 | |
| | Radionuclides and blood parameters in fish from Beaverlodge Lake. | 30 | |
| | Laboratory study plan for effects of radionuclides on aquatic fauna. | 32 | |

| | | |
|---|---|---|
| Benthological, chemical, radiological and chronological evaluation of sediments in Port Hope harbour. | 34 | |
| Benthological, chemical, radiological and chronological evaluation of sediments in Serpent River harbour. | 35 | |
| Saskatchewan Mining Development Corporation (SMDC) | | |
| Evaluation of current predictive models for radiation exposure limits in uranium mines. | 4 | |
| Evaluation of operational and post-operational impacts and monitoring data for uranium mining projects. | 5 | |
| Saskatchewan Research Council (SRC) | | |
| Study of abnormalities in fish blood and blood-forming tissues in relation to radonuclide and heavy metal accumulation. | 13 | SRC report E-901-40-E-84 |
| Novel application of statistical methods to the analysis of radionuclide distribution in vegetation. | 17 | SRC report E-902-5-B-85 |
| Distribution of naturally occurring radionuclides in freshwater benthos and their environment. | 18 | Joint SENES/SRC report: Contact V. Cassaday. Senes Consultants, Willowdale, Ont. or NUTP. |

JOINT PANEL ON OCCUPATIONAL AND ENVIRONMENTAL RESEARCH
FOR URANIUM PRODUCTION IN CANADA

## MATRIX OF RESEARCH AREAS

| | OCCUPATIONAL | ENVIRONMENTAL |
|---|---|---|
| DEFINE<br>CONDITIONS OF EXPOSURE | AECB 32,62,80,81,82.<br>AECL 15,20,21.<br>CAIRS 2,3.<br>EMR 2.3.<br>MOL 1.<br>NHW 11.<br>SCR 16. | AECB 58,70,36.<br>AECL 1a,b,c,2.<br>DOE 5,11,14.<br>MNR 2.<br>MOE 4,5.<br>SRC 11,12,17,18,20. |
| IDENTIFY<br>ADVERSE EFFECTS | AECB 77.<br>AECL 17,18,20,21.<br>EMR 2.1,2.2,2.3.<br>MOL 1. | AECL 17,18.<br>DEN 20.<br>DOE 21.<br>EMR 2.1,2.3,4.1,4.2.<br>IAN 1,2,3. |
| RELATE<br>EXPOSURE WITH EFFECT | AECB 66,68,79.<br>AECL 13,17,18,19,20,21.<br>MOL 1.<br>NHW 3 (AECB 5). | AECL 13,17,18.<br>SRC 13. |
| ASSESS<br>RISK | AECB 52,53,57,64,65,76,78.<br>AECL 13.<br>CAIRS 1.<br>DEN 17.<br>MOL 1.<br>NHW 5.<br>RIO 13.<br>SMDC 4. | AECB 71,84.<br>AECL 1c,2,13.<br>DEN 18,19.<br>DOE 16.<br>SMDC 4,5. |
| CONTROL<br>HAZARD | AECB 72,74,75.<br>EMR 2.4.<br>NHW 6,10. | AECB 69,83.<br>AECL 11.<br>DOE 15.<br>EMR 2.4.<br>MNR 1.<br>RIO 3,19. |

FORM 4/84

## PUBLICATION FILE

The first Annual Report of the Joint Panel for Occupational and Environmental Research for Uranium Production in Canada was produced in 1977.

This publication file contains references for only the current year, 1985, and the two preceding years, 1983 and 1984. The annual report for 1983 contains all previous lists of publications, as do earlier annual reports.

Publications should be obtained from the public literature or from the organization conducting or sponsoring the work.

The publication list includes specific project reports by member agencies, as well as other reports of relevance not necessarily associated with the projects listed in the Active Projects section.

### Atomic Energy Control Board (AECB) Publications: Listings for 1983

1. Dory, A.B., "The regulatory process for uranium mines in Canada - general overview and radiation health and safety in uranium mine - mill facilities", INFO-0082.

2. Bragg, K., Potter, C., James, A., "Recent developments in the regulation and management of Canadian uranium tailings", INFO-0103.

3. Stocker, H., Horvath, F.J. and Napier, W. "Recommendations concerning an interim annual individual occupational exposure limit for respirable quartz", INFO-0100.

4. Bragg, K., Boulden, R., "Uranium tailings in Canada - regulation and management", INFO-0099.

5. Davis, M.W., Monserco Ltd., "Correlation analysis of first phase monitoring results for uranium mill workers", INFO-0098.

6. IEC Beak Consultants Ltd., "An approach to the calculation of dose commitment arising from different methods for the long-term management of uranium tailings - summary report", INFO-0097.

7. Monserco Ltd., "Testing and evaluation of existing techniques for identifying uptakes and measuring retention of uranium in mill workers", INFO-0094.

8. Yoshida, K., Atiemo, M.A., Markham, J.W., "Field measurements of mixed exposures of operators to radioactive aerosol, gas and quartz in confinement of mining equipment cabs during open-pit mining of high-grade uranium ore", INFO-0093.

### Atomic Energy Control Board (AECB) Publications: Listings for 1984.

1. Veska, E., Cherry, J.A., Sharma, H.D., University of Waterloo, "Origin and subsurface migration of radionuclides from waste rock at an abandoned uranium mine near Bancroft, Ontario", (314 p), INFO-0105.

Atomic Energy Control Board (AECB) Publications: Listings for 1985.

1. Phillips, .R., Khan, A., Leung, H., "Development of diffusion - based radon daughter dosimeters", INFO-0012.

2. R.A.D. Service and Instruments Ltd., "Design of the passive personal dosimeter for mines using an allyl diglycol carbonate plastic - phase I: basic and feasibility study", INFO-0117.

3. Corkill, D.A., Dory, A.B., "A retrospective study of radon daughter concentrations in the workplace in the fluorspar mines of St. Lawrence, Newfoundland", INFO-0127.

4. Chiu, N.W., Dean, J.R., Sill, C.W., "Techniques of sample attack used in soil and mineral analysis - phase I", INFO-0128-1.

5. Archibald, J.F., "Membrane barriers for radon gas flow restrictions", INFO-0130.

6. Friesen, Kaye and Associates, "An evaluation of the uranium mine radiation safety course", INFO-0182,

7. Ching, S.H., "Derived surface contamination limits for the uranium mining and milling industry", INFO-0138.

8. IEC Beak Consultants Ltd., "Probabilistic calculation of dose commitment from uranium mill tailings", INFO-0139.

9. Linauskas, S.H., Kalos, F., "Study of the efficiency and current use of respiratory protective devices", INFO-0144.

10. Senes Consultants Ltd., "Computer modelling of an underground mine ventilation system", INFO-0145.

11. Avadhanula, M.R., "Dissolution studies of $UO_2$ in simulated lung fluid", INFO-0147.

12. Dean, J.R., Chiu, N.W., "Analysis of techniques of sample attack for soil and mineral analysis - phase II", INFO-0128-2.

13. DSMA Atcon Ltd., "Elliot Lake study: factors affecting the uranium mine working environment prior to the introduction of current ventilation practices", INFO-0154.

Atomic Energy of Canada Ltd. (AECL): Listings for 1983

1. Johnson, J.R. and Dunford, D.W., "Dose conversion factors for intakes of selected radionuclides by infants and adults", Report AECL-7919 (1983).

2. Kramer, G.H., Gardner, S.E. and Johnson, J.R., "Screening procedures for alpha, beta and gamma emitting radionuclides in urine", Report AECL-7608 (1983).

3. Johnson, J.R. "Dose conversion factors used in the current Canadian high level waste disposal assessment study", Report AECL-7869. Radiation Protection Dosimetry vol. 3, (1/2), 47, 1982.

4. Johnson, J.R., "An age dependent model for radium metabolism in man". Published in special Conf. Proc. issue of Health Physics of Int. Conf. on the Radiobiology of Radium and the Actinides in Man, Lake Geneva, Wisconsin, Oct. 11-16, 1981. Report AECL-7612. Health Physics vol. 44, (1), 91-102, 1983.

5. Johnson, J.R., James, A.C. and Birchall, A., "An estimation of the bronchial cancer risk from the inhalation of long-lived alpha emitting radionuclides", Proc. of Special Workshop on Lung Dosimetry, Radiation Research Society meeting, Salt Lake City, Utah, April 1982. Published in "Current Concepts in Lung Dosimetry", Edited by D.R. Fisher, 1982.

6. Johnson, J.R. and Peterman, B.F., "A model to describe thoron exhalation following an inhalation exposure to thoria powders", to be published in Conf. Proc. of Workshop on Lung Modelling for Inhalation of Radioactive Materials, Oxford, U.K., March 1984 (in preparation).

7. Kramer, G.H. and Beaulieu, P.C., "The determination of radium-226 in urine", Report AECL-7979, 1983.

8. Desai, N. and Kramer, G.H., "An improved radiochemical method for the isolation of uranium from other actinides in urine", Report AECL-7986 1983.

9. Evans, D.W.S., Marko, A.M. and Myers, D.K., "Effects of ionizing radiation", Letter to Editor. Can. Med. Assoc. J., vol 129, 10-11, 1983.

10. Marko, A.M. and Myers, D.K., "The effects of ionizing radiation and review of the Young-Woollard document", Report AECL-8061, 1983.

11. McGregor, J.F. (with revisions by D.K. Myers), "Enhancement of skin tumorigenesis by cigarette smoke condensate following beta-irradiation in rats", J. Natl. Cancer Inst. vol 68, pp 605-611, 1982.

12. Myers, D.K., "Follow-up of irradiated human populations", pp 39-66 in Uranium and Nuclear Issues, Proc. of Seminar, Canadian Nuclear Assoc. 1983.

13. Walton, F.B., Melnyk, T.W., Abry, P.G. and Fleury, K., "The determination of radionuclide-geologic media reaction kinetics using mixing cell contactors", Report AECL-7391, Chem. Geol. vol. 36, 155, 1982.

14. Walton, F.W., Melnyk, T.W., Ross, J.P.M. and Skeet, A.M.M., "Determination of radionuclide sorption mechanisms and rates on granitic rock by selective chemical extraction techniques", Int. Symp. of Geochemical Behaviour of Disposal Radioactive Wastes, Am. Chem. Soc. Meeting, Seattle, March 1983, in press.

15. Melnyk, T.W., Walton, F.B. and Johnson, J.H., "High-level waste glass field burial tests at CRNL: the effect of geochemical kinetics on the release and migration of fission products in a sandy aquifer", Report AECL-6836, 1983.

16. Goodwin, B.W. and Lyon, R.B., "A review of computer models for assessment of the long-term behaviour of uranium tailings", WNRE-COO-1032 (DSS File No. 15 SQ. 23440-2-9148; CANMET Project No. 23440-2-9148), 1983.

17. Moltyaner, G.L., "An approximate analytical procedure for solving a radionuclide transport equation", Proc. Int. Conf. on Radioactive Waste Management, Winnipeg, 12-15 Sept. 1982. (Canadian Nuclear Society).

18. Milton, G.M. and Brown, R.M., "Uranium series disequilibrium in rock-water systems of the Canadian Shield", Pres. by Milton at IAEA Symp. on Isotope Hydrology in Water Resource Development, Vienna, 12-16 Sept. 1983. (Full paper to be published.)

19. Brown, R.M., Killey, R.W.D. and Lee, D.R., "Isotope hydrology techniques used in studies at Chalk River", A poster presentation at IAEA Symp. on Isotope Hydrology in Water Resource Develoment, Vienna, 12-16 Sept. 1983. (Abstract to be published).

20. Champ, D.R. and Merritt, W.F., "Particulate transport of cesium in groundwater, Proc. of 2nd Annual Conf. of the Canadian Nuclear Society, (F.N. McDonnell, Ed.), 1981.

21. Champ, D.R., Inch, K.J., Killey, R.W.D., Lee, D.R. and Sheppard, M.I., "Geochemistry in the Biosphere from the pluton to the plant", in Environmental and Safety Assessment, Proc. of 13th Nuclear Fuel Waste Management Information Meeting, 1982.

22. Champ, D.R., Merritt, W.F. and Young, J.L., "Potential for the rapid transport of plutonium in groundwater as demonstrated by core column studies", in Scientific Basis for Nuclear Waste Management V, (W. Lutze, Ed.), 1982.

23. Killey, R.W.D. and Moltyaner, G.L., "Hydrodynamic dispersion in a 20-metre natural gradient tracer test", in Proc. of 15th Information Meeting of the Nuclear Fuel Waste Management Meeting, Toronto, 12-13 June 1983.

24. Cornett, J.R., "Nuclide sedimentation in lakes", Proc. of 15th Information Meeting of the Nuclear Fuel Waste Management Meeting, Toronto, 12-13 April 1983.

25. Killey, R.W.D., McHugh, J.O., Champ, D.R., Cooper, E.L. and Young, J.L., "Subsurface Co-60 migration from a low-level waste disposal site", Environmental Science and Technology, 1984.

26. Lee, D.R., "Groundwater discharge zone, presented by R.W.D. Killey at 15th Waste Management Information Meeting, Toronto, 12-13 April 1983.

27. Sheppard, M.I., Sheppard, S.C. and Thibault, D.H., "Identification of the problem phytotoxicant in soil from a radioactive waste disposal area", Whiteshell Nuclear Research Establishment Report WNRE-461, 1982.

28. Iverson, S.L., Barnard, J., Cornett, R.J., Johnson, J.R., Killey, R.W.D., Lee, D.R., Reimer, A., Sheppard, M.I. and Zach, R., "Environmental research for the Canadian nuclear fuel waste management program", Report TR-150, Atomic Energy of Canada Ltd., 1982.

29. Sheppard, M.I., Thibault, D.H. and Guthrie, J.E., "Radiosensitivity and the role of Pinus sylvestris L. in the revegetation of radioactive disposal areas", Environ. Exp. Bot. vol 22 (2), 193-198, 1982.

30. Zach, R., Crichton, V.F.J., Stewart, J.M. and Mayoh, K.R., "Early winter food habits of Manitoba moose as determined by three rumen analysis methods", Can. J. Zool, 60 (6): 1300-1304.

31. Zach, R., "Parameter values for the long-term nuclear waste management food chain model LIMCAL", Report AECL-6828, 1982.

32. Zach, R., "LIMCAL: a comprehensive food chain model for predicting radiation exposure to man in long-term nuclear waste management", Report AECL-6827, 1982.

33. Zach, R. and Mayoh, K.R., "The transfer of fallout $^{137}Cs$ from browse to moose - Part 1: moose food habits", Report AECL-6832, 1982.

34. Zach, R., "Preliminary probability density functions for the parameters of the food chain model LIMCAL", Report TR-205, Atomic Energy of Canada Ltd., 1982.

35. Iverson, S.L., "Canadian environmental research for nuclear waste management", Proc. of Canadian Nuclear Society Int. Conf. on Radioactive Waste Management, Winnipeg, Manitoba, pp 554-560, 1982.

36. Iverson, S.L., "Environmental research", Report TR-207, Atomic Energy of Canada Ltd., 1982.

37. Sheppard, M.I. and Thibault, D.H., "$^{NAT}U$ concentration factor distributions for ten plant species indigenous to the Precambrian Shield", Report TR-220, Atomic Energy of Canada Ltd., 1983.

38. Zach, R. and Mayoh, K.R., "Caloric contents of diets for environmental assessment models: a necessary condition", Health Physics 45: 786-789, 1983.

39. Mayoh, K.R. and Zach, R., "Generic LIMCAL dose/concentration ratios for 57 radionuclides ingested by infant and adult man", Report TR-214, Atomic Energy of Canada Ltd., 1983.

40. Zach, R. and Sherman, G.R., "LIMCAL-S: a comprehensive stochastic food chain model for nuclear waste disposal concept assessment", Report TR-232, Atomic Energy of Canada Ltd., 1983.

41. Davis, P.A., "Suspension and short-range atmospheric transport", in Proc. 15th Nuclear Fuel Waste Management Information Meeting, Report TR-216, Atomic Energy of Canada Ltd., 1983.

42. Sheppard, S.C., "Plant uptake and redistribution", Proc. 15th Nuclear Fuel Waste Management Information Meeting", Report TR-216, Atomic Energy of Canada Ltd., 1983.

43. Zach, R., "The food chain model LIMCAL", Proc. 15th Nuclear Fuel Waste Management Information Meeting, Report TR-216, Atomic Energy of Canada Ltd., 1983.

Atomic Energy of Canada Ltd. (AECL): Listings for 1984


1. Werner, M.M. and Myers, D.K., "Biological effects of radiation", Manual for Uranium Mine Radiation Safety Course, Canadian Institute for Radiation Safety, 1984.

2. Kramer, K.G., Johnson, J.R. and Green, W., "The measurement of natural uranium in urine by fluorometry", Report AECL-8251, February 1984.

3. Johnson, J.R., "Age dependent metabolism and dosimetry of bone seeking radionuclides", published in Conf. Proc. of 6th Int. Congr. of the Int. Radiation Protection Assoc., IRPA, West Berlin, pp 485-488, May 1984.

4. Johnson, J.R., Kramer, G.H. and Peterman, B.F. "Internal dosimetry monitoring at the Chalk River Nuclear Laboratories", Published in Conf. Proc. of 6th Int. Congr. of the Int. Radiation Protection Assoc., IRPA, West Berlin, pp 988-991, May 1984.

5. Johnson, J.R. "A review of the dosimetry from inhalation of long-lived alpha activity in ore dust", Published in Conf. Prof. of the Int. Conf. on Occupational Radiation Safety in Mining, Toronto, Ont., October 1984.

6. Myers, D.K. and Johnson, J.R. "Impact of occupational hazards on the life expectancy of uranium miners", published in the Conf. Proc. of the Int. Conf. on Occupational Radiation Safety in Mining, Toronto, Ont. Oct. 1984.

7. Johnson, J.R. and Dunford, D.W., "Canadian uranium fuel fabrication study, Part II: comparison of results of metabolic models", published in Conf. Proc. of the Int. Symp. on the Assessment of Radioactive Contamination in Man, IAEA-SM-276/51, Paris, France, November 1984.

8. Champ, D.R. "Microbial mediation of radionuclide transport - significance for the nuclear fuel waste management program", Report AECL-8566. 1984.

9. Cooper, E.L., McHugh, J.O., "Migration of radiocontaminants in a forested wetland on the Canadian Shield: nuclide speciation and arboreal uptake", in The Science of the Total Environment, vol 28, pp 215-230, 1983.

10. Davison, C.C., Pearson, R. and Whitaker, S.H., "Site investigation methods used in Canada's nuclear fuel waste management program to determine the hydrogeological conditions of plutonic rock", Proc. of IAEA Workshop on Site Investigation and Assessment Methods for Nuclear Waste Disposal, Bulgaria, 1984.

11. Killey, R.W.D., McHugh, J.O., Champ, D.R., Cooper, E.L. and Young, J.L., "Subsurface cobalt-60 migration from a low-level waste disposal site", Env. Sci. & Tech., vol. 18, p 148, March 1984.

12. Killey, R.W.D. and Myrand, D., "The movement of water, arsenic, and radium at a Chalk River waste management area", Report AECL-8639, 1984.

13. Moltyaner, G.L. and Paniconi, C., "Migration of radionuclides in unconsolidated materials: analysis of experimental data", Report AECL-8254.

14. Moltyaner, G.L., "Migration of radionuclides in unconsolidated materials: equilibrium transport models", Report AECL-8253.

15. Osborne, R.V. (Editor), "Long-term radiological aspects of the management of wastes from uranium mining and milling", Nuclear Energy Agency, OECD, Paris, France, 1984.

16. Abdul, A.S. and Gillham, R.W., "Laboratory studies of the effects of the capillary fringe on streamflow generation", Water Resources Research, vol 20, No. 6, pp 691-698, June 1984.

17. Cramer, J.J., "Uranium deposits as analogs to fuel waste disposal vaults", in Proc. of 17th Information Meeting of the Nuclear Fuel Waste Management Program, Ottawa, 1984.

18. Fleer, V.N. and Garisto, N.C., "Mineral stability and thermodynamic models", Proc. of 17th Information Meeting of the Nuclear Fuel Waste Management Program, Ottawa, 1984.

19. Gascoyne, M., "Uranium series disequilibrium studies of shield rocks and groundwater", Proc. of 17th Information Meeting of the Nuclear Fuel Waste Management Program, Ottawa, 1984.

20. Sargent, F.P., "Geochemistry: an overview", Proc. of 17th Information Meeting of the Nuclear Fuel Waste Management Program, Ottawa, 1984.

21. Vandergraaf, T.T., "Radionuclide migration - laboratory studies", Proc. of 17th Information Meeting of the Nuclear Fuel Waste Management Program, Ottawa, 1984.

22. Davison, C.C., "Hydrogeological characterisation at the site of Canada's underground research laboratory", Proc. of Int. Groundwater Symp. on Groundwater Resources Utilization and Contaminant Hydrogeology of the Int. Assoc. of Hydrogeologists, Montreal, Quebec, pp 310-335, 1984.

23. Pearson, R., "An overview of hydrogeological field research in the Canadian nuclear fuel waste management program", Proc. of Int. Groundwater Symp. on Groundwater Resources Utilization and Contaminant Hydrogeology of the Int. Assoc. of Hydrogeologists, Montreal, Quebec, pp 484-497, 1984.

Atomic Energy of Canada Ltd. (AECL): Listings for 1985

1. Avadhanula, M.R., Chatterjee, R.M., Healey, G.J., Horvath, F.J., Measures, M.P., Stocker, H., Pomroy, C., Johnson, J.R. and Dunford, D.W., "Canadian uranium fuel fabrication study: I intake, retention and excretion monitoring results. II comparison of results with metabolic models. Symp. on the Assessment of radioactive contamination in man", Intern. Atomic Energy Agency, Vienna, pp. 297-323, 1985.

2. Champ, D.R., Young, J.L., Robertson, D.E., Abell, K.H., "Chemical speciation of long-lived radionuclides in a shallow groundwater flow system", Water Pollution Research J. of Canada, 19, 35-54, 1984.

3. Champ, D.R., Moltyaner, G.L., Young, J.L. and Lapcevic, P., "A downhole column technique for field measurement of transport parameters", AECL-8905, 1985.

4. Davis, J.L., Killey, R.W.D., Annan, A.P. and Vaughan, C., "Surface and borehole ground penetration radar surveys for mapping geological structure", Proc. of the NWWA/EPA Conf. on Surface and Borehole Geophysical Methods, February 07-09, 1984.

5. Jay, P.C., "Anion contamination of environmental water samples introduced by filtration procedures", Analytical Chemistry, v.57, No. 3, pp 780-782, 1985.

6. Jay, P.C. and Judd, J.M., "The determination of common anion concentrations in surface and groundwater samples by eluent suppressed ion chromatography", Intern. J. Environ. Anal. Chem., v.19, pp. 99-109, 1984.

7. Johnson, J.R., "The relative effect of ventilation on the potential α-energy from $^{222}Rn$ and $^{220}Rn$ progeny, Health Physics 49, pp 996-998, 1984.

8. LaFleur, D.W., Pickens, J.F. and Killey, R.W.D., "Hydrogeologic assessment of the 233-Lake area: calibration of a 3-D groundwater model", TR-257, 1985.

9. Lee, D.R. "Method for locating sediment anomalies on lakebeds that can be caused by groundwater flow", J. Hydrol. 79, 197-193, 1985.

10. Male, D.H., "Wind transport of soil aerosols", Technical Record, TR-295, 1985.

11. Moltyaner, G.L., Sudicky, E.A. and Cherry, J.A., "Contaminant transport in heterogeneous porous media: characterization of spatial variability and dispersivity at a field site", Technical Record, TR-258, 1985.

12. Munch, J.H. and Killey, R.W.D., "Equipment and methodology for sampling and testing cohesionless sediments", Groundwater Monitoring Review, vol. 5, No. 1, pp 38-42, 1985.

13. Patterson, M.C., Gentner, N.E., Middlestadt, M.V., Mirzayans, R. and Weinfeld, M., "Hereditary and familial disorders linking cancer proneness with abnormal carcinogen response and faulty DNA metabolism", Epidemiology and Quantitation of Environmental Risks in Humans from Radiation and Other Agents, pp 235-267, Plenum Corp., 1985.

14. Peterman, B.F., "Thoron-in-breath monitoring at CRNL", Report AECL-8706, 1985.

15. Olivier, J.P., Osborne, R.V. and Rafferty, P.J., "Long-term management of uranium mill tailings: results of the OECD/NEA study", AECL-8499, 1984.

16. Sheppard, M.I., "Radionuclide partition coefficients in soils and plants and their correlation", Health Physics, 49, pp 106-111, 1985.

17. Sheppard, M.I. and Sheppard, S.C., "The plant concentration factor concept as applied to natural uranium", Health Physics 48, pp 494-500, 1985.

18. Wuschke, D.M., Gillespie, P.A. and Main, D.E., "Second interim assessment of the Canadian concept for nuclear fuel waste disposal. vol. 1 - summary", Report AECL-8373-1, 1985.

Canadian Institute for Radiation Safety (CAIRS): Listings for 1983

1. Sputum Cytology Program - Annual Report, 1982-83.

2. Radiation Safety Bulletin, vol 1, No. 1, 1983.

3. Guidelines for Safety - Changing to SI Radiological Units.

4. Second Annual Report, CAIRS, 1982-83.

Canadian Institute for Radiation Safety (CAIRS): Listings for 1984

1. Third Annual Report, CAIRS, 1983-84.

2. Radiation Safety Bulletin, vol 2, No. 1, 1984.

Canadian Institute for Radiation Safety (CAIRS): Listings for 1985

1. CAIRS Annual Report, March 31, 1985.

2. "Determination of the contribution of long-lived dust to the committed dose equivalent received by uranium mine and mill workers in the Elliot Lake area", report on research completed under contract to the Atomic Energy Control Board of Canada, November 1985.

3. "The uranium mine radiation safety course", UMRSC 2/85, October 1985.

4. "Radiation safety training in uranium mines and mills: a CAIRS proposal", 1985. Title amended in February 1986 to "Radiation safety training in uranium and other mines and mills".

5. "Progress report on CEA dosimeter performance", December 1985.

6. "Proposal: modified personal alpha dosimeter for Canadian uranium mines", January 1986.

7. "Lung cancer detection, a CAIRS program for Ontario uranium miners", January 1986.

8. "Radiation? who cares? CAIRS cares / CAIRS. Qu'est-ce que c'est?" a bilingual brochure on CAIRS' purpose, programs and activities.

9. "Radiation safety bulletin", vol. 4, No. 1, April 1986. Bulletin de radioprotection.

Energy, Mines and Resources Canada (EMR): Listings for 1983

1. Grenier, M., Bigu, J. and Hallman, E.D., "On the attachment of decay products of radon to aerosols in the submicron range", Division Report MRP/MRL 83-6(J), CANMET, Energy, Mines and Resources Canada, 1983.

2. Bigu, J. and Lau, W., "Determination of the thoron daughter working level by a one gross alpha method", Division Report MRP/MRL 83-13(TR), CANMET, Energy, Mines and Resources Canada, 1983.

3. Bigu, J. and Grenier, M., "Studies of radioactive dust in Canadian uranium mines", CIM Bull. vol 77, No. 869, p 62, Sept. 1984.

4. Lim, T.P., Dave, N.K. and Vivyurka, A., "Groundwater flow pattern in Nordic West Arm tailings area", Division Report MRP/MRL 83-34(TR), CANMET, Energy, Mines and Resources Canada, 1983.

5. Bigu, J., "Description of an automated, computer-based continuous monitoring system for the determination of the short-lived decay products of radon and thoron", Division Report MRP/MRL 83-38(TR), CANMET, Energy, Mines and Resources Canada, 1983.

6. Bigu, J., Raz, R., Golden, K. and Dominguez, P., "Design and development of a computer-based continuous monitor for the determination of the short-lived decay products of radon and thoron", Nuclear Instrum. and Methods in Phys. Res., vol 225, pp 399-406, 1984.

7. Bigu, J., "Identification and measurement of long-lived radioactive dust by gamma and alpha spectroscopy", Division Report MRP/MRL 83-48(OP), CANMET, Energy, Mines and Resources Canada, 1983.

8. Dave, N.K. and Lim, T.P., "Migration of contaminants from underwater buried pyritic uranium tailings - laboratory investigations of Ra-226 transfer flux", Division Report MRP/MRL 83-49(OP), CANMET, Energy, Mines and Resources Canada, 1983.

9. Bigu, J., "Progress during the first half of 1983 in the environmental projects of the CANMET minerals program", Division Report MRP/MRL 83-50(OP), CANMET, Energy, Mines and Resources Canada, 1983.

10. Cloutier, N.R., Clulow, F.V., Vivyurka, A., Dave, N.K. and Lim, T.P., "Metals (Cu, Ni, Co, Zn, Pb) and radionuclide (Ra-226) levels in meadow voles (Microtus pennsylvanicus) established on revegetated copper and nickel tailings in Copper Cliff and uranium tailings in Elliot Lake", Division Report MRP/MRL 83-53(TR), CANMET, Energy, Mines and Resources Canada, 1983.

11. Bigu, J. and Roze, V., "Extended capabilities of a personal alpha-dosimeter as an environmental radon (thoron) daughter continuous monitor", Radiation Protection Dosimetry, vol. 8, No. 3, pp 173-176, 1984.

12. Bigu, J. and Grenier, M., "Thoron daughter working level measurements by one and two gross alpha-count methods", Nuclear Instrum. and Methods in Phys. Res. vol 225, pp 385-398, 1984.

13. Bigu, J., "Theoretical models for determining radon and thoron daughter levels in Canadian underground uranium mines - a comparison with experimental data", Health Phys. vol 48, No. 4, pp 371-399, April 1985.

14. Grenier, M. and Bigu, J., "Evaluation and calibration of a continuous radon gas monitor using the Thomas method", Division Report MRP/MRL 83-62(TR), CANMET, Energy, Mines and Resources Canada, 1983.

15. Bigu, J., "Design and performance of a personal alpha-dosimeter of the passive type for radon daughters using a diffused-junction detector and an electrostatic collector", Radiation Protection Dosimetry, vol 5, No. 3, pp 171-178, 1984.

16. Bigu, J., Kaldenbach, R. and Grenier, M., "Design and performance of a microprocessor-based automated continuous monitor with alpha-spectroscopy capabilities for the determination of radon and thoron and their short-lived decay products", Division Report MRP/MRL 83-78(TR), CANMET, Energy, Mines and Resources Canada, 1983.

17. Bigu, J., "Description, design and operation of a large radon/thoron test facility of the walk-in-type for testing and calibration of radiation instrumentation and other studies", Published under the title A Walk-In Radon/Thoron Test Facility. Am. Ind. Hyg. Assoc. J. vol 45, No. 8, pp 525-534, 1984.

18. Grenier, M. and Bigu, J., "Analysis of seasonal variations in soil temperature at a uranium tailings disposal site - a comparison with theoretical data", Division Report MRP/MRL 83-84(TR), CANMET, Energy, Mines and Resources Canada, 1983.

19. Bigu, J., "Use of an automated fluxmeter employing solid-state diffused-junction alpha-detectors and a meteorological package to determine surface radon flux", IEEE Transactions on Nuclear Science, vol NS-31, No. 6, pp 1599-1606, December 1984.

20. Bigu, J., Kaldenbach, R. and Grenier, M., "Theory and operation of a time-integrating, continuous, radon daughter monitor", Division Report MRP/MRL 83-87(TR), CANMET, Energy, Mines and Resources Canada, 1983.

21. Bigu, J., Grenier, M., Dave, N.K., Lim, T.P. and Chakravatti, J.L., "Study of radon gas concentration, surface radon flux and other radiation variables from uranium mine tailings areas", Uranium, vol 1, pp 257-277, 1984.

22. Bigu, J., "Progress during the second half of 1983 in the environmental projects of the CANMET minerals program", Division Report MRP/MRL 83-102(OP), CANMET, Energy, Mines and Resources Canada, 1983.

23. Bigu, J., Raz, R., Golden, K. and Dominguez, P., "A computer-based continuous monitor for the determination of the short-lived decay products of radon and thoron", Proc. Conf. of Health Phys. Soc. on Computer Applications in Health Phys., Midyear Topical Meeting, Pasco, WA, Feb 1984.

24. Bigu, J., Grenier, M., Dave, N.K., Lim, T.P. and Chakravatti, J.L., "Radon gas concentration, surface radon flux and other radiation variables from uranium mine tailings areas", Proc. 6th Annual Symp. on Management of Uranium Mill Tailings, Low-Level Waste and Hazardous Waste, Fort Collins, Colorado, February 1984. pp 211-220.

25. Dave, N.K. and Lim, T.P., "Migration of contaminants from underwater buried uranium tailings - laboratory investigations of Ra-226, total dissolved solids, Ca+2 and SO4-2 transfer flux", Proc. 6th Annual Symp. on Management of Uranium Mill Tailings, Low-Level Waste and Hazardous Waste, Fort Collins, Colorado, February 1984, pp 83-92.

26. Bigu, J., Brown, L., Chakravatti, J.L., and Champ, D., "On the role of the Joint Panel - recommendations by a working group", Division Report MRP/MRL 83-106(OP,J), CANMET, Energy, Mines and Resources Canada, 1983.

27. Silver, M., "Leaching characteristics of uranium tailings from Ontario and Northern Saskatachewan", Division Report MRP/MAL 83-99(J), CANMET, Energy, Mines and Resources Canada, June 1983.

28. Dave, N.K. and Lim, T.P., "Coaxial groundwater sampling pump for hydrogeochemical investigations", Promotech 1983, Office of Technology Transfer, CANMET, Energy, Mines and Resources Canada, 1983.

Energy, Mines and Resources Canada (EMR): Listings for 1984

1. Dave, N.K., Lim, T.P. and Cloutier, N., "Radionuclide levels within various tissues of vegetation growing on uranium tailings in Elliot Lake", Division Report MRP/MRL 84-5(TR), CANMET, Energy, Mines and Resources Canada, 1984.

2. Bigu, J. and Vandrish, G., "Radon (thoron) daughter measurements with an automated programmable radiation monitor", Division Report MRP/MRL 84-14(J), CANMET, Energy, Mines and Resources Canada, 1984.

3. Dave, N.K., Lim, T.P. and Cloutier, N., "Radionuclide uptake by various plants growing on uranium tailings, Elliot Lake, Ontario", Division Report MRP/MRL 84-19(TR), CANMET, Energy, Mines and Resources Canada, 1984.

4. Bigu, J., "Theoretical considerations regarding the emanation of radon and thoron gases from underground uranium mine walls", Division Report MRP/MRL 84-26(J), CANMET, Energy, Mines and Resources Canada, 1984.

5. Grenier, M. and Bigu, J., "Etude des descendants du radon fixee aux aerosols de taille sous-micronique", MRP/MRL 84-38(TR), CANMET, Energy, Mines and Resources Canada, 1984.

6. Bigu, J., "Effect of electric fields on thoron daughter concentration", Division Report MRP/MRL 84-40(J), CANMET, Energy, Mines and Resources Canada, 1984.

7. Grenier, M. and Bigu, J., "The use of a statistical model for estimating monthly soil temperatures in uranium tailings disposal sites", Division Report MRP/MRL 84-41(J), CANMET, Energy, Mines and Resources Canada, 1984.

8. Bigu, J., "Radon daughter and thoron daughter deposition velocity and unattached fraction under laboratory-controlled conditions and in underground uranium mines", Proc. 29th Annual Meeting of Health Society, New Orleans, June 1984.

9. Bigu, J., "Progress during the first half of 1984 in the environmental projects of the CANMET minerals program", presented at Joint Panel meeting, Elliot Lake, June 1984.

10. Bigu, J. and Frattini, A., "A radon (thoron) daughter personal alpha-dosimeter of the passive type using a diffused-junction detector and an electrostatic collector", Division Report MRP/MRL 84-60(TR), CANMET, Energy, Mines and Resources Canada, 1984.

11. Bigu, J. and Raz, R., "A passive radon/thoron personal dosimeter using an electrostatic collector and a diffused-junction detector", Division Report MRP/MRL 84-68(J), CANMET, Energy, Mines and Resources Canada, 1984. Rev. Sci. Instrum, vol. 56, No. 1, pp 146-153, 1985.

12. Grenier, M. and Frattini, A., "Calibration procedures and protocols for radiation sampling pumps and alpha-particle scalers", Division Report MRP/MRL 84-77(TR), CANMET, Energy, Mines and Resources Canada, 1984.

13. Cloutier, N., Lim, T.P. and Dave, N.K., "Use of small mammals for geomonitoring environmental radionuclide levels around mining industries", Division Report MRP/MRL 84-80(TR), CANMET, Energy, Mines and Resources Canada, 1984.

14. Bigu, J., "Radon daughter and thoron daughter deposition velocity and unattached fraction under laboratory-controlled conditions and in underground uranium mines", Division Report MRP/MRL 84-91(J), CANMET, Energy, Mines and Resources Canada, 1984. J. of Aerosol Science, vol. 16, No. 2, pp 157-165, 1985.

15. Bigu, J., "Removal of airborne thoron (radon) daughters on mine walls and other surfaces by convective deposition and electrostatic plate-out", Proc. Int. Conf. on Occup. Radiation Safety in Mining, Toronto, Ont., October 1984.

16. Bigu, J., "Non steady-state radiation mine model - practical applications to personal dosimetry and environmental monitoring", Proc. Int. Conf. on Occup. Radiation Safety in Mining, Toronto, Ont., October 1984.

17. Dave, N.K., Lim, T.P. and Cloutier, N., "Ra-226 concentrations in blueberries (Vaccinium Angustifolium Ait.) near an inactive uranium tailings site in Elliot Lake, Ontario", Division Report MRP/MRL 84-95(J), Canmet, Energy, Mines and Resources Canada, 1984.

18. Bigu, J., "A method for determining thoron gas concentrations", Proc. Conf on Environmental Radiation '85, Colorado Springs, CO, January 1985.

19. Dave, N.K., Cloutier, N. and Lim, T.P., "Radionuclide levels in vegetation growing on uranium tailings", Proc. 7th Annual Symp. of Management of Uranium Tailings, Low-Level Waste and Hazardous Waste, vol II, pp 263-271, 1985.

20. Bigu, J., "Progress during the second half of 1984 in the environmental projects of the CANMET minerals program", Presented at Joint Panel Meeting, Saskatoon, Sask, November 1984.

Energy Mines and Resources Canada (EMR): Listings for 1985

1. Dave, N., Lim, T.P. and Cloutier, N., "Ra-226 concentrations in blueberries (Vaccinium Angustifolium Ait.) near an inactive uranium tailings site in Elliot Lake, Ontario, Canada", Division Report MRP/MRL 85-28, CANMET, Energy, Mines and Resources Canada, 1985.

2. Bigu, J., "Theory of diffusion of radon and thoron through membranes under steady-state and time-dependent radiation conditions - part I (steady-state case)", Division Report MRP/MRL 85-51, CANMET, Energy, Mines and Resources Canada, 1985.

3. Bigu, J., "Theory of diffusion of radon and thoron through membranes under steady-state and time-dependent radiation conditions - part II (time-dependent case)", Division Report MRP/MRL 85-52, CANMET, Energy, Mines and Resources Canada, 1985.

4. Bigu, J., "Theoretical considerations regarding the behaviour of a mine model with ventilation under time-dependent radiation conditions", Division Report MRP/MRL 85-53, CANMET, Energy, Mines and Resources Canada, 1985.

5. Bigu, J., "Theoretical considerations regarding the growth and decay of the short-lived decay products of radon and thoron plated-out on large surfaces", Division Report MRP/MRL 85-54, CANMET, Energy, Mines and Resources Canada, 1985.

6. Grenier, M., "Program ALPHAPRINT for the processing of data acquired by an AlphaNUCLEAR Ltd. logger system", Division Report MRP/MRL 85-64, CANMET, Energy, Mines and Resources Canada, 1985.

7. Bigu, J., "Thoron determination using activated carbon and a high purity germanium detector", Division Report MRP/MRL 85-71, CANMET, Energy, Mines and Resources Canada, 1985.

8. Bigu, J. and Frattini, A., "Radon progeny and thoron progeny plate-out on a variety of materials", Division Report MRP/MRL 85-72, CANMET, Energy, Mines and Resources Canada, 1985.

9. Bigu, J., "Theoretical considerations regarding active sampling of time-dependent radon (thoron) atmospheres", Division Report MRP/MRL 85-75, CANMET, Energy, Mines and Resources Canada, 1985.

10. Dave, N., Lim, T.P. and Cloutier, N., "Migration of metals and trace radionuclides from mine tailings to the environment", Division Report MRP/MRL 85-80, CANMET, Energy, Mines and Resources Canada, 1985.

11. Bigu, J. and Grenier, M., "Characterization of radioactive dust in Canadian underground uranium mines", Division Report MRP/MRL 85-81, CANMET, Energy, Mines and Resources Canada, 1985.

12. Grenier, M., "On-filter self-absorption and loading characteristics", Division Report MRP/MRL 85-83, CANMET, Energy, Mines and Resources Canada, 1985.

13. Bigu, J., "Theory and application of radon and thoron progeny monitoring under steady-state and non-steady-state radiation conditions - part I: active sampling", Division Report MRP/MRL 85-88, CANMET, Energy, Mines and Resources Canada, 1985.

14. Bigu, J., "Progress during the first half of 1985 in the environment projects of the CANMET minerals program", presented to Joint Panel at Chalk River, Ontario, 25-26 June, 1985. Division Report MRP/MRL 85-90, CANMET, Energy, Mines and Resources Canada, 1985.

15. Bigu, J., "Theory and application of radon and thoron progeny monitoring and steady-state and non-steady-state radiation conditions - part II: passive sampling", Division Report MRP/MRL 85-91, CANMET, Energy, Mines and Resources Canada, 1985.

16. Bigu, J., "The effect of time-dependent ventilation rates in partially enclosed radioactive environments", Division Report MRP/MRL 85-92, CANMET, Energy, Mines and Resources Canada, 1985.

17. Bigu, J. and Kaldenbach, R., "A microprocessor based continuous monitor with alpha-spectroscopy capabilities for the determination of radon, thoron and their progeny", Division Report MRP/MRL 85-115, CANMET, Energy, Mines and Resources Canada, 1985.

18. Bigu, J. and Grenier, M., "Electrical characteristics of the short-lived decay products of thoron in underground mines", Division Report 85-116, CANMET, Energy, Mines and Resources Canada, 1985.

19. Bigu, J., "Plate-out of radon and thoron progeny on different materials", Division Report MRP/MRL 85-117, CANMET, Energy, Mines and Resources Canada, 1985.

20. Bigu, J., "A method for determining thoron and radon gas concentrations using solid-state alpha-particle detectors", Division Report MRP/MRL 85-120, CANMET, Energy, Mines and Resources Canada, 1985.

21. Bigu, J., "An automated multisensor apparatus for comparative membrane radon and thoron permeability studies", Division Report MRP/MRL 85-123, CANMET, Energy, Mines and Resources Canada, 1985.

22. Bigu, J., "Attachment of radon and thoron progeny to the surface of different materials", Division Report 85-130, CANMET, Energy, Mines and Resources Canada, 1985.

23. Bigu, J., "Progress during the second half of 1985 in the environment projects of the CANMET minerals program", presented to the Joint Panel in Toronto, December 1985. Division Report MRP/MRL 86-1, CANMET, Energy, Mines and Resources Canada, 1986.

24. Bigu, J., "Theoretical models for determining radon and thoron daughter levels in Canadian underground uranium mines - a comparison with experimental data", Health Physics vol 48, No. 4, pp 371-399, April 1985.

25. Bigu, J., "Use of an automated fluxmeter employing solid-state diffused-junction alpha-detectors and a meteorological package to determine surface radon flux", IEEE Transactions on Nuclear Science, vol NS-31, No. 6, pp 1599-1606, December 1984.

26. Bigu, J., "Effect of electric fields on $^{220}$Rn progeny concentration", Health Physics (Note), vol 49, No. 3, pp 512-516, September 1985.

27. Bigu, J. and Raz, R., "A passive radon/thoron daughter personal dosimeter using an electrostatic collector and a diffused-junction detector", Rev. Sci. Instrum., vol 56, No. 1, pp 146-153, 1985.

28. Bigu, J., "Radon daughter and thoron daughter deposition velocity and unattached fraction under laboratory-controlled conditions and in underground uranium mines", J. Aerosol Science vol 16, No. 2, pp 157-165, 1985.

29. Bigu, J., "Removal of airborne thoron (radon) daughters on mine walls and other surfaces by convective deposition and electrostataic plate-out", Proc. Int. Conf. on Occup. Radiation Safety in Mining 1984.

30. Bigu, J., "Non steady-state radiation mine model - practical applications to personal dosimetry and environmental monitoring", Proc. Int. Conf. on Occup. Radiation Safety in Mining 1984.

31. Bigu, J., "A method for determining thoron gas concentrations", Proc. Conf. Environmental Radiation '85, Colorado, January 1985.

32. Dave, N., Lim, T.P. and Cloutier, N., "Ra-226 concentrations in blueberries (Vaccinium Angustifolium Ait.) near an inactive uranium tailings site in Elliot Lake, Ontario, Canada", Environ. Poll. Series B, vol 10, pp 301-314, 1985.

33. Dave, N., Lim, T.P. and Cloutier, N., "Migration of metals and trace radionuclides from mine tailings to the environment", Proc. Int. Conf. on Heavy Metals in the Environment, Athens, Greece, September 1985.

34. Bigu, J. and Grenier, M., "Characterization of radioactive dust in Canadian underground uranium mines", Proc. 2nd U.S. Mine Ventilation Congr., Reno, Nevada, 1985, pp 269-279.

35. Bigu, J., "The effect of time-dependent ventilation rates in partially enclosed radioactive environments", Proc. Ventilation Congr., Toronto, Ont., October 1985.

36. Bigu, J. and Kaldenbach, R., "A microprocessor based continuous monitor with alpha-spectroscopy capabilities for the determination of radon, thoron and their progeny", Radiation Protection Dosimetry, vol 12, No. 3, pp 251-260, 1985.

Environment Canada (DOE): Listings for 1983

1. Robinson, D., Ruggles, R. and Zaidi, A., "A study of water pollution in the vicinity of Gulf Minerals Rabbit Lake, 1978", Environmental Protection Service Report EPS-5-W&NR-83-1, Environment Canada, 1983.

2. Kalin, M., "Long-term ecological behaviour of abandoned uranium mill tailings I, synoptic survey and identification of invading biota", Environmental Protection Service Report EPS-4-ES-83-1, Environment Canada, 1983.

Environment Canada (DOE): Listings for 1984

1. Constable, M., "Annotated Bibliography of environmental impact work at uranium mine/mills in Saskatchewan", Environmental Protection Service, Western and Northern Region, 1983.

2. Lawson, D.W., "Preliminary report on spill of mine and tailings water, Key Lake uranium mine, Northern Saskatchewan, January 5-7, 1984", Environmental Protection Service, Western and Northern Region, 1984.

3. Kalin, M., "Environmental conditions of two abandoned uranium mill tailings sites in Northern Saskatchewan", SDOE Contract No. 32 (81-82) Saskatchewan Environment and Environmental Protection Service, 1982.

4. Ruggles, R.G., Robinson, D. and Zaidi, A., "A study of water pollution in the vicinity of two abandoned uranium mills in Northern Saskatchewan 1978", Environmental Protection Service Report EPS-WNR-5-81-2.

5. Kalin, M., "Rayrock Northwest Territories uranium tailings and environment", a report to Environment Canada and Indian & Northern Affairs Canada (Contract No. OSG 83-00074), 1984.

6. Raven, K.G. and Novakowski, K.S., "Field investigations of the solute-transport properties of fractures in a monzonite gneiss", Proc. Internal Groundwater Symp., vol II, pp 507-516, 1984.

7. Bottomley, D.J. et al., "A borehole methodology for hydrogeochemical investigations in fractured rock", Water Resour. Res., vol 20, No. 9, pp 1277-1299, 1984.

8. Bottomley, D.J. et al., "Helium and neon isotope geochemistry of some groundwaters from the Canadian Shield", Geochem. Cosmochem. Acta, vol 48, pp 1973-1985, 1984.

9. Novakowski, K.S., et al., "Determination of groundwater flow pathways in fractured plutonic rock using a radioactive tracer". Int. I. App.l. Rad. and Isotopes, 1984 (in press).

10. Raven, K.G. et al., "Borehole hydrogeologic investigations at the East Bull Lake research area, summary of 1983 activities", Report to AECL by NHRI.

11. Raven, K.G. et al., "Borehole hydrogeologic investigations at the East Bull Lake research area", paper presented at the 17th Information meeting of AECL Nuclear Waste Management Program.

## Bibliography of Environment Canada Publications on Uranium Mining in Saskatchewan

1. "A study of water pollution in the vicinity of Gulf Minerals Rabbit Lake 1978", Environmental Protection Service, Surveillance Report EPS 5-W&NR-83-1.

2. "Annotated bibliography of environmental impact work at uranium mine/mills in Saskatchewan", Environmental Protection Service, Western and Northern Region, 1983.

3. "Preliminary report on spill of mine and tailings water, Key Lake uranium mine, Northern Saskatchewan, January 5-7, 1984", Environmental Protection Service, Western and Northern Region, 1984.

## Environment Canada (DOE): Listings for 1985

1. "Removal of radium-226 from uranium mining effluents", A final report of a Joint Government-Industry Program, Environment Canada Report No. EPS 3/H/3, 1984.

2. "Joint government-industry program for the removal of radium-226 from uranium mining effluents", Final reports vol II, and vol III (Appendices), 1984.

3. W&W RECS., "Assessment of radiological impact of non-uranium metal mining", Environment Canada report No. IP-21, 1984.

4. Kalin, M., "Long-term ecological behaviour of abandoned uranium mill tailings - 2. Growth patterns of indigenous vegetation on terrestrial and semi-aquatic areas", Report No. EPS 3/HA/2, 1984.

5. Platford, R.F., FitzGerald, J.A., Bobba, A.G. and Joshi, S.R., "Report on the groundwater at the Port Granby radioactive waste management site from 1981 to 1983", Environment Canada, National Water Research Institute, Unpublished report No. 84-9, 1984.

6. Platford, R.F., Bobba, A.G. and Joshi, S.R., "The Port Granby radioactive waste management site", Water Poll. Res. J. Canada vol 19, No. 2, pp 90-96, 1984.

7. Kalin, M., "Port Radium Northwest Territories, an evaluation of environmental effects of the uranium and silver tailings", A report to Environment Canada, Dept. of Indian & Northern Affairs, Health & Welfare Canada, Fisheries and Oceans, 1984.

8. Reardon, E.J. and Moddle, P.M., "Peat moss as an oxygen interceptor material for the management of pyritic uranium tailings", Environment Canada report No. IP-22, 1984.

9. Monenco Analytical Laboratories, "Investigation to remove arsenic and radium-226 from Port Granby effluent using manganese impregnated filters", Report to Eldorado Resources Ltd., and Environment Canada, 1984.

10. Swanson, S., "Laboratory study plan for uptake and effects of radionuclides in aquatic fauna", Environment Canada and Saskatchewan Research Council, SRC Publication No. E-901-13-E-84, 1984.

11. Swanson, S. and Bernstein, J., "Physiological parameters in three fish species from Beaverlodge area, Saskatchewan", Environment Canada, SRC Publication No. E-901-40-E-84, 1984.

12. Raven, K.G., Novakowski, K.S. and Bottomley, D.J., "Hydrogeologic research at the Chalk River research area", Paper presented at the 16th AECL Information Meeting of the Nuclear Fuel Waste Management Program, Winnipeg, September 1983.

13. Novakowski, K.S., Raven, K.G. and Evans, G.V., "A review of radionuclide migration experiments conducted in a plutonic rock environment at CRNL", Paper presented at the 17th AECL Information meeting on Nuclear Fuel Waste Management Program, Ottawa, 1984.

14. Raymond, L. and Lawson, D.W., "Uranium library Saskatchewan district office, Environmental Protection Service", Environment Canada, W&NR, Regina, 1985.

15. Joshi, S.R., "Cs-137, Ra-226 and total uranium in fish from lakes Ontario, Erie, Huron and Superior during 1976-1982", Water Poll. Res. J. Canada, vol 19, pp 110-119, 1984.

16. Joshi, S.R., "Recent sedimentation rates and Pb-210 fluxes in Georgian Bay and Lake Huron", Sci. Total Environment, vol 41, p. 219, 1985.

17. Platford, R.F. and Joshi, S.R., "The chemistry of uranium and related radionuclides in Lake Ontario waters", manuscript in preparation.

18. Novakowski, K.S., Flavelle, P.A., Raven, K.G. and Cooper, E.L., "Determination of groundwater flow pathways in fractured plutonic rock using a radioactive tracer", Int. J. Appl. Radiat. Isot., vol 36, No. 5, p. 399, 1985.

19. Novakowski, K.S., Evans, G.V., Lever, D.A. and Raven, K.G., "A field example of measuring hydrodynamic dispersion in a single fracture", Water Resources Res. vol 21, No. 8, pp 1165-74, 1985.

20. "A study to assess the distribution of radionuclides in the aquatic ecosystem in the vicinity of the Serpent River mouth", A report to Environment Canada, EPS-Ontario Regina by Beak Consultants Ltd., 1985.

Health and Welfare Canada (NHW): Listings for 1983

1. Pomroy, C. and Limson Zamora, M., "The establishment of a quality assurance program for radiobioassay measurements in Canada". Proc. of 29th Annual Conf. on Bioassay, Analytical and Environmental Chemistry, Seattle, Washington, October 1983.

Health and Welfare Canada (NHW): Listings for 1984

1. Limson Zamora, M., "The establishment of a national calibration centre for practical standards for bioassay and in vivo monitoring". Proc. of Int. Conf. on Occupational Radiation Safety in Mining, October 1984.

2. Pomroy, C. and Malm, H., "Hyperpure germanium detectors for in vivo measurements of uranium and thorium". Proc. of IAEA Sypm. of the Assessment of Radioactive Contamination in Man, Paris 1984. In press.

3. Avadhanula, M.R., Chatterjee, R.M., Healey, G.J., Horvath, F.J., Measures, M.P., Stocker, H., Pomroy, C. and Johnson. J. "Canadian uranium fuel fabrication study - I: Intake retention and excretion monitoring results"; and "Canadian uranium fuel fabrication study - II: Comparison of results to metabolic models". Proc. of IAEA Symp. on the Assessment of Radioactive Contamination in Man, Paris 1984, pp. 297-323, IAEA, Vienna, 1985.

Ministry of the Environment, Ont. (MOE): Listings for 1984

1. "Serpent River basin water quality data, 1982", Technical Support Section, Northeastern Region, Ontario Ministry of the Environment 1984.

Ministry of the Environment, Ont. (MOE): Listings for 1985

1. "Ambient air quality assessment studies carried out in the Elliot Lake area, January 1982 to March 1984".

   (High volume and dustfall sampling indicate that the 1982-83 particulate levels are comparable to 1976-77 levels, when the monitoring program began. Comparison of radionuclide levels with control locations in the Northeastern region indicate that only uranium is slightly higher in the Elliot Lake area.)

Saskatchewan Dept. of Environment: Listings for 1985

1. Barsi, R.G., "Present status of uranium mill tailings in Saskatchewan", presented at the Engineering of Waste Management Systems Seminar, Saskatoon, Saskatchewan, August 1985.

2. Beak Consultants Ltd., "An environmental evaluation of the effects of the Eldor Mines Rabbit Lake operations on Wollaston Lake", prepared for Saskatchewan Environment, November 1985.

3. Morin, K.A., "Simplified explanations and examples of computerized methods for calculating chemical equilibrium in water", Computers and Geosciences, vol. 11, No. 4, pp 409-416, 1985.

4. "Radon surveys in Saskatchewan", Saskatchewan Environment, MPCB, March 1985.

Saskatchewan Research Council (SRC): Listings for 1983

1. Arnold, R.G., "Uranium mine and mill tailings management in Canada: present status and future directions", Proc. of Int. Conf. on Radioactive Waste Management. IAEA-CN-43/136, 1983.

2. Swanson, S.M., "Levels of $^{226}Ra$, $^{210}Pb$, and $^{total}U$ in fish near a Saskatchewan uranium mine and mill", Health Phys. 45(1):67-80, 1983.

3. Tones, P.I., "Limnological and fisheries investigation of the flooded open pit at the Gunnar uranium mine", SRC Publ. No. C-805-10-E-82. Prepared for the Mines Waste Research Secretariat, Saskatchewan Environment, 1982.

4. Whiting, J., Christiansen, E., Heuser, H., Kermeen, J.S., Maathuis, H. and Machibroda, P., "Summary report on the surface water and groundwater investigations of the Larado mill area and meteorology data for the Gunnar uranium tailings", vol. 1 and 2, SRC Publ. No. E-820-4-E-82, 1982.

5. Yoshida, K. and Atiemo, M., "Characteristics of aerosols in the vicinity of equipment cabs in open pit mining of uranium", Aerosol in Mining and Industrial Work Env., vol. 2, Chapter 33. Characterization, Marple and Liu (Ed.), Ann Arbor Science, Michigan, 1983.

Saskatchewan Research Council (SRC): Listings for 1984

1. Barnes, J. and Lehtinen, J., "Radium removal from Canadian uranium mining effluents by a radium selective ion exchange complexer: radium removal using a radium selective complexer", SCR-R-836-1-C-84, Confidential, 1984.

2. Dyck, J., McKenzie, C. and Tones, P., "Acquisition and transformation of Saskatchewan Research Council proprietary data by use of a prototype microcomputer system for the Canadian uranium tailings data base (CANUT), SRC-R-852-2-C-84, 1984.

3. Senes Consultants Ltd. and Saskatchewan Research Council for the National Uranium Tailings, "A study of the distribution of naturally occurring radionuclides in freshwater benthos and their environment, Phase I report", Senes Consultants, 499 McNicoll Ave., Willowdale, Ont. M2H 2C9, 1984.

4. Sheard, J.W., "A preliminary study of radionuclide distributions in the upland vegetation of Northern Saskatchewan", Dept. of Biology, University of Saskatchewan, Saskatoon, 1984.

5. Swanson, S.M., "Food chain transfer of uranium-series radionuclides in a northern aquatic system", Health Phys. (Accepted). MS available from author at SRC, 30 Campus Drive, Saskatoon, Sask., 1984.

Saskatchewan Research Council (SRC): Listings for 1985

1. Swanson,S.M., 1985, "Food chain transfer of U-series radionuclides in a Northern Saskatchewan aquataic system", Health Physics, 49(5):747-770, 1985.

2. Swanson, S.M., Tones, P.I. and Richert, D., "Compilation and statistical analysis of a data base on uranium-series radionuclides in aquatic biota in Northern Saskatchewan", Interim Report SRC Publ. No. E-901-5-E-85, 1985.

3. Swanson, S.M. and Bernstein, J., "Physiological parameters in three fish species in the Beaverlodge area", SRC Publ. No. E-901-40-E-84, 1984.

4. Sheard, J.W., "A preliminary study of radionuclide distributions in the upland vegetation of northern Saskatchewan. SRC Publ. No. E-902-5-B-85, 1985.

5. Swanson, S.M., "A study of the distribution of naturally occurring radionuclides in freshwater benthos and their environment". Phase II Report. Senes Consultants Ltd., Willowdale, Ontario. 1985.

## SUPPORTING MEMBER REPRESENTATIVES - 1985

1. Atomic Energy of Canada Limited
   Chalk River Nuclear Laboratories,
   Chalk River, Ont. K0J 1J0

   Dr. D.K. Myers — 613-584-3311
   Head, Biology Branch — 613-687-5581

   Alternate:
   D. Champ,
   Environmental Research Branch

2. Atomic Energy Control Board,
   P.O. Box 1046,
   Ottawa, Ontario, K1P 5S9

   Dr. H. Stocker, — 613-995-2866
   Chief, Regulatory Research Branch
   Health Effects and Regulatory Documents Section

   Alternate:
   E. Rabin, — 613-995-2981
   Regulatory Research Branch,
   Health Effects and Regulatory Documents Section

3. Canadian Centre for Occupational Health and Safety,
   Health Sciences Centre,
   250 Main St. East,
   Hamilton, Ont. L8N 1H6

   Mr. B. Pathak,
   Manager, Technical Resources Development — 416-527-6590

4. Canadian Institute for Radiation Safety,
   P.O. Box 460,
   Elliot Lake, Ont. P5A 2J9

   Dr. E. Becker, Senior Scientist — 705-848-3687

5. Cigar Lake Mining Corp.,
   410 - 224 Fourth Ave, S.
   Saskatoon, Sask. S7K 5M5

   Mr. M. Senior — 306-665-2628

6. Denison Mines Ltd.,
P.O. Box B2600,
Elliot Lake, Ont. P5A 2K2

Mr. J.L. Chakravatti, 705-461-6250
Sr. Environmental Engineer

7. Eldorado Resources Limited,
255 Albert Street,
Ottawa, Ont. K1P 1C1

Dr. A. Ashbrook 613-238-5222

8. Energy, Mines and Resources Canada,
Mining Research Laboratories,
CANMET, E.M.R.,
Elliot Lake Laboratory,
P.O. Box 100, Elliot Lake,
Ontario P5A 2J6

Dr. J. Bigu, Research Scientist 705-848-2236
Project Leader, Radiation, Ventilation & Respirable Dust

9. Environment Canada,
Les Terrasses de la Chaudiere, 23rd Floor,
Ottawa, Ont. K1A 0H4

Dr. E.F. Roots, 819-997-2393
Office of the Science Advisor

Alternate:
Dr. P. Vasudev 819-997-1220

10. Health and Welfare Canada,
Health Protection Branch,
Radiation Protection Bureau,
Brookfield Road,
Ottawa, Ontario K1A 1C1

Dr. M. Limson-Zamora 613-993-9715

11. Northern Environment Directorate,
Terrestrial Environment Branch,
Indian and Northern Affairs Canada,
Les Terrasses de la Chaudiere,
Ottawa, Ontario K1A 0H4

Dr. M. Barnett, 819-994-7458
Environmental Geologist

12. Key Lake Mining Corporation
229C 4th Avenue S.,
Saskatoon, Sask. S7K 4K3

Mr. L. Price 306-665-7000

13. Ministry of Labour, Ontario,
400 University Avenue,
Toronto, Ontario M7A 1T7

Dr. H. Aitken, Chief — 416-965-8178
Radiation Protection Service,
Special Studies and Services

14. Rio Algom Limited
P.O. Box 1500
Elliot Lake, Ontario P5A 2K1

Mr. E. Barnes, — 705-461-4455
Research Superintendent
Process Development

15. Saskatchewan Environment
Mines Pollution Control Branch
12th Floor, 800 Central Avenue
P.O. Box 3003, Prince Albert,
Saskatchewan S6V 4V1

Mr. C. Potter, Manager — 306-953-2219
Technical Services Section

16. Saskatchewan Labour
Occupational Health and Safety Branch,
1870 Albert Street,
Regina, Saskatchewan S4R 3V7

Dr. L.D. Brown, — 306-787-4486
Chief Radiation Health Specialist

17. Saskatchewan Mining Development Corporation,
122 - 3rd Avenue N.,
Saskatoon, Saskatchewan S7K 2H6

Mr. C.H. Burton, — 306-933-6207
Sr. Scientist, Environmental

18. United Steelworkers of America
92 Frood Road,
Sudbury, Ontario P3C 4Z4

Mr. H. Seguin, — 705-675-2461
Regional Representative

Alternate:
Mr. Ed Vance — 705-848-2226
20 Alberta Road,
Elliot Lake, Ontario P5A 1Z6

JOINT PANEL ON OCCUPATIONAL AND ENVIRONMENTAL RESEARCH
FOR URANIUM PRODUCTION IN CANADA

APPENDIX

| DATE | STATEMENT OF PROJECT | PROJECT # |
|---|---|---|
| | | |

| TITLE | MATRIX LOCATION |
|---|---|
| | |

| OBJECTIVE |
|---|
| |

| SCOPE OF WORK | |
|---|---|
| | ANTICIPATED COST |

| RESEARCHER(S) | ANTICIPATED COMPLETION DATE |
|---|---|
| | |

| SPONSOR(S) | CONTACT |
|---|---|
| | |

FORM 1/84

JOINT PANEL ON OCCUPATIONAL AND ENVIRONMENTAL RESEARCH
FOR URANIUM PRODUCTION IN CANADA

| DATE | REPORT ON PROJECT PROGRESS | PROJECT # |
|---|---|---|
| | | |

| TITLE | MATRIX LOCATION |
|---|---|
| | |

| PROGRESS/STATUS |
|---|
| |

| CHANGES | ANTICIPATED COST |
|---|---|
| | ANTICIPATED COMPLETION DATED |

| SPONSOR(S) | CONTACT |
|---|---|
| | |

FORM 2/84

JOINT PANEL ON OCCUPATIONAL AND ENVIRONMENTAL RESEARCH
FOR URANIUM PRODUCTION IN CANADA

| DATE | PROJECT COMPLETION REPORT | PROJECT # |
|---|---|---|
| | | |

| TITLE | MATRIX LOCATION |
|---|---|
| | |

DISPOSITION/STATUS

(Please quote abstract of publication if appropriate)

| PUBLICATION AVAILABILITY | FINAL COST |
|---|---|
| | |

| SPONSOR(S) | CONTACT |
|---|---|
| | |

FORM 3/84